RAIL TECHNOLOGY

IN THE TWENTIETH CENTURY

Prepared by
R.S. Wallace & Associates Limited

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FOREWORD

In 1978 the Commission sponsored a study by R.S. Wallace and Associates on Truck and Rail Technological Developments to 1990. Because of the interest in that work, it was decided to commission R.S. Wallace and Associates to prepare a study on Rail Technology in the Twentieth Century which is a review of railway technological developments and the current progress and problems.

The report examines six major technological areas including locomotives, fuels, electrification, freight cars, marshalling yards and trackage. Each section recounts the historical developments since 1945, reviews current state-of-the-art technologies and identifies expected near future innovations. The relationship between technology and technological developments are examined. A final section contains selected scenarios of future developments.

This report is released as a contribution to public discussion on the important issue of technological change in transport. The opinions expressed are those of the consultant and do not necessarily reflect the views of the Canadian Transport Commission.

Yves Dubé
Vice-President (Research)

Canada

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EXECUTIVE SUMMARY

The study of Rail Technology in the Twentieth Century provides an overview of historical and future technological development in the rail industry. It is intended to update and expand upon the rail portion of a 1978 study; Truck and Rail Technological Developments to 1990. The report examines six major technological areas including locomotives, fuels, electrification, freight cars, marshalling yards and trackage. Each section recounts the historical developments since 1945, reviews current state-of-the-art technologies and identifies expected near future innovations. In a separate section, productivity trends and their relation to technological developments are examined. A final section speculates on the direction of long term future development based on selected scenarios and influencing factors. The highlights of the report are summarized below.

Locomotives

Beginning with the introduction of the first diesel-electric locomotives to Canadian road service in 1948, some 3 100 diesel units rapidly replaced 5 000 steam engines as a source of motive power. With the introduction of the exhaust gas driven turbo-charger in 1959 the second generation diesels took a quantum leap in power. The trend towards ever increasing power outputs continued up until fuel prices started to rise rapidly in 1973. More recent developments have been aimed at improving fuel economy, reliability, and maintenance rather than increasing power.

Current third generation locomotives costing approximately $950 000 each, have increased fuel economy 7% over previous models. This amounts to roughly 2 100 gallons of fuel per year per locomotive. With further engine refinements, higher traction locomotives, improved operating procedures, better maintenance and education, further increases in fuel economy of 2% per year are possible. Locomotive designs in the near future will continue to evolve as refinements of current models become more automated and as technology improves the interface between computer and hardware. The role of the operator will increasingly be to monitor operations and provide manual back-up.

Longer term technologies include development of dual-mode electric/diesel-electric locomotives, wayside energy storage systems, diesel locomotives powered by substitute fuels and Rankine Cycle Turbines for recapturing waste exhaust energy.

Alternate Fuels

Alternate fuels for use in diesel engines include hybrid, substitute, broadcut, and synthetic fuels. Synthetic tar sand fuels already supply 6% of rail demand and are used without modification to the engines. Broadcut or off-specification diesel fuel can increase refinery yields by 5% and can be used with little or no engine modification. Hybrid fuels such as alcohol diesel mixes can replace up to 32% of an engine's energy requirement with minor engine modifications. Specific fuel consumption would increase about 16%, since alcohol has only half the heat content of diesel fuel. Hybrid fuel prototypes should be in service by 1985. Substitute fuels which replace diesel fuel will require major engine modifications. For the future, hydrogen is the most promising substitute fuel since it is clean burning, does not come from petroleum feedstocks and has twice the heat content of diesel fuel.

Future fuel supplies for transportation in general will likely include a wide variety of fuel types rather than any one dominant form. The railroad industry, however, will favour a limited number of alternate fuels in order to standardize equipment and facilities.

Electrification

Mainline electrification of Canada's railroads now appears to be only a matter of time. Railroads themselves generally favour conversion if the initial capital cost barrier can be overcome. Cost estimates vary widely, but are in the range of $1 million per mile for motive power and fixed plant equipment. Annual savings in energy costs, maintenance, and life cycle costs of locomotives are estimated to be $70 000 per route-mile. This constitutes a 7% return on the $1 million per mile cost to electrify and clearly shows that on fuel savings alone, electrification is not justified. Electrification of high density main lines has the potential to reduce rail diesel fuel consumption by 50% or 270 million gallons per year. The most likely timing for the initiation of electrification is in the mid-1990's.

Freight Cars

Current designs will not likely increase above 265 000 lbs. gross weight unless there is a move to six-axle cars, since axle loadings are now at their maximum. Tare weight reduction of four or five tons and high utilization of freight cars, can increase their ton-mile productivity some 10% in the near future. New articulated flat car designs can save as much as 300 000 gallons (U.S.) per year in a single C/TOFC train. Roadrailers, which are multimode rail/highway trailers, are now being tested in revenue service and promise further fuel economy increases and reductions in capital costs.

Conventional C/TOFC carriers may evolve into separate units designed for carrying containers or trailers but not both.

New articulated flatcar designs, because of their lighter weight, can cut fuel consumption by 25% compared to conventional flatcars. Roadrailers which are multimode rail/highway trailers can cut fuel consumption by 50% compared to conventional flatcars. The units, costing approximately $33 000 each, offer a significant capital saving over flatcars.

Traffic Control Systems

In traffic control systems the key to future development will be the computer. It has the ability to increase system capacity without resorting to major capital investments. As the headway between trains is shortened, the capacity of the line is increased. Computers also take over many of the clerical duties allowing dispatchers to devote more time to higher order functions of traffic control, thereby increasing safety and efficiency. Traffic control systems will be one of the more important developments in the future.

Computers on board the locomotive will contribute to improved train control, better fault detection, and minimize headway between trains when used in conjunction with wayside detectors and transmitters.

Automatic car identification systems will be introduced in the near future, using passive or active transmitters on the freight cars to overcome the reliability problems had with previous photo-electric type sensors.

Marshalling Yards

Yards continue to increase automation through computer applications. This will reduce freight terminal time, increase yard capacity and reduce labour intensive activities.

In the marshalling yard, the current hump yard design will remain in North America. Computers and automation are acting to increase capacities of existing yards thereby foregoing large capital investments in new yards.

Modern computerized yards, for example, can easily reduce freight car terminal times from 18 to 12 hours. Future development will be aimed at process control which interfaces the computer with the hardware in the yard. Other future developments will bring such technologies as freight cars with automatically coupling brake lines and radio controlled yard locomotives.

Trackage

Continuous welded rail and concrete ties are being used for track replacements in heavy grade and curve areas.

Concrete ties are claimed to last 50 years compared to 30 years for wooden ones. As well, the concrete tie reduces maintenance costs by 30%.

Geotextiles are now being used in areas where water is a problem in the roadbed. They act as wicks which draw water out to the sides of the road.

Large track machines capable of lifting old rail and ties, performing all maintenance functions and relaying new rail and concrete ties in one operation are proving effective. Estimates of rail replacement savings run as high as $3 million per year. Smaller mobile highway/rail machines will be used increasingly to perform single spot maintenance functions between major track changeouts. Design of future track maintenance equipment will concentrate on making it simpler, dependable, more automated and above all, faster in order to carry out maintenance operations between the increasing number of train movements.

Productivity Trends

The table on page 5 summarizes the increased productivity of various inputs from 1945 to 1978 and the factors which influenced them.

Long Term Outlook

The external factors which influence technological development in the rail industry include energy, capital, labour, demand, government policy regulation and safety. Energy is the most significant factor. It will most likely detemine the policy on electrification, the future of alternate fuel development and encourage research in fuel efficient technologies. Capital is the second most important factor. In the capital intensive rail industry, new technologies which are proven effective will not be implemented if the capital is not available.

PRODUCTIVITY INCREASES

	1945	1962	1978	Influencing Factors
Labour (ton-miles/employee)	300 000	400 000	1 200 000	retiring employees, dieselization
Energy (ton-miles per million Btu's)	376	1 512	1 900	dieselization, high capacity freight cars, current locomotive refinements
Freight Cars (ton-miles/car)	388 000	326 000	750 000	higher capacity, better load factors, higher utilization, lower tare weight
Locomotives (annual ton-miles/ locomotive)	14 000 000	17 700 000	34 000 000	dieselization, higher availability, turbo-charging, tractive effort improvements, higher freight car capacity
Track (annual ton-miles/ mile)	1 000 000	1 100 000	2 400 000	abandonment of low density lines, heavier trains, centralized traffic control

Chapter 1

INTRODUCTION

1.1 Background

This report has been prepared to extend and update the rail portion of a previous 1978 study Truck and Rail Technological Developments to 1990. The new report's objective is to provide an overview of technological developments, their implications, timing and the likelihood of implementation into the rail freight industry. The time frame is from the end of World War II to the year 2000. Discussions concentrate on current developments now in the testing stage and implementation within the next 10 years. No attempt is made to provide detailed technical descriptions of technologies, but rather an overview is presented of "what it is, what it does and what are its effects".

The major topics of discussion include: locomotives, alternate fuels, electrification, freight cars, traffic control, trackage and freight marshalling yards. Separate sections are also presented on productivity trends as they relate to technological developments, and the direction of long term technological change as it relates to various scenarios and influencing factors.

Historically there has been a reluctance to introduce new technologies into highly standardized fleets of railroad equipment. In an operation where locomotives last some 20 years and freight cars serve for 30 years, the turnover in technology has been slow. Development has been primarily an evolutionary process. Today's locomotives for example are basically more refined versions of the same units first introduced in 1948.

However, the environment has been changing over the last five years. Railroads are now showing an increasingly receptive attitude towards innovative concepts. In particular, major studies are being made in computer applications to railroading. There is an abundance of new electronic technology available to the industry. The limiting factor is primarily the availability of capital to implement new developments.

1.2 Authorization

This study was authorized by the Research Branch of the Canadian Transport Commission by requisition Number 0-8340, dated 25 November 1980, with the Consultant Firm of R.S. Wallace & Associates Limited.

1.3 Justification and Scope of the Report

The report is prepared as a contribution to understanding the current and future capabilities of freight railroads in Canada's transportation industry. It covers technological developments in the rail freight industry from 1945 to the present. It reviews current state-of-the-art and near-future technologies and speculates on some of the long term developments within hypothesized future scenarios.

Limitations on the study size prevents the developments from being examined in exhaustive detail. Instead, a wide range of topics is discussed in an overview manner. As such, this report will be of interest to those responsible for directing and regulating the rail freight industry.

The report is presented from the rail operator's point of view describing technologies and their impacts on industry.

1.4 Limitations

The level of effort of some three man-months assigned to this study limits the depth of analysis of each of the topics examined. In keeping with the study's purpose, it provides an overview of technological changes.

1.5 Sources of Information

The examination of the wide range of topics in this study drew upon information from an equally broad range of information sources. The major published sources appear in the list of references at the end of the report. In addition, information was gathered by visits and phone conversations with researchers in the rail industry.

1.6 Organization of Presentation

Chapter 1, presents the purpose and scope of the study with statements on authorization for the study, limitations on its scope, sources of information and format of presentation. Chapters 2, through 8 deal with locomotives, alternate fuels, electrification, freight cars, traffic control systems, marshalling yards and railway trackage. Each chapter portrays the history of development, current state-of-the-art and expected near-future technologies in a particular field of the industry. Chapter 9 relates productivity trends in freight rail transportation to technological developments over time. Chapter 10 presents a long term outlook for the types of technologies which will develop under various scenarios and environmental influencing factors. Chapter 11 summarizes by chapter the highlights of the report.

1.7 Summary of Conclusions

The main points in the report are summarized as follows:

a) Development of locomotives will continue to be evolutionary with fuel economy gradually increasing in the range of 2% per year. Future locomotives will be operated increasingly under automatic control as computers assume more responsibility for train operations.

b) Alternate fuels for use in diesel engines appear in a variety of forms requiring varying degrees of engine modification. Long term engine effects and hardware modifications are the subject of ongoing research. Hybrid fuel prototypes should be in road service by 1985.

c) Electrification now appears to be only a matter of time. Railroads are generally in favour of conversion to electricity if the initial capital cost barrier can be overcome. The first stages of electrification could start by 1995.

d) Freight cars are now designed for maximum axle loading and designers are striving to achieve higher payloads by reducing tare weights. Higher ton-mile productivity will result through greater utilization, shorter terminal times and higher load factors. Light weight articulated flatcars will likely be the next step in C/TOFC carriers. Highway/rail intermodal "Roadrailers" are proving effective in preliminary tests and should also gain in popularity as a low cost, fuel efficient alternative to piggyback TOFC carriers.

e) Traffic control systems will use more computer applications to increase line capacity without major capital investments. The result will be safer high density operation.

f) Marshalling yards are becoming increasingly automated to increase capacity, reduce labour content and reduce terminal times.

g) In the future, railroad tracks will use more concrete ties and alloy steels to reduce maintenance requirements on high density lines. Maintenance equipment will evolve into both large machines able to replace track in one operation and smaller mobile rail/highway machines for carrying-out spot maintenance. Maintenance equipment developments will stress the importance of minimizing the time required on the tracks.

h) Labour productivity has increased by a factor of four since 1945. Conversion from steam to diesel power and the reduced number of employees resulted in this increase. In other areas, energy productivity also showed a six-fold increase due to dieselization and more recently with fuel economy improvements in locomotive and train operation.

i) In the future environments for railroading, energy will be the most significant factor leading research towards more fuel efficient designs and alternate energy concepts. The availability of capital will be an important factor governing the implementation of new concepts.

Chapter 2

LOCOMOTIVES

2.1 Overview

Chapter 2 begins with a brief review of locomotive developments since World War II. This is followed by a review of historical and near-future developments of specific components and locomotive subsystems. The technological developments, their significance, and introduction into service are described in an overview manner. Included are related developments in the areas of:

a) prime movers;

b) fuel efficiency;

c) maintenance and reliability;

d) remanufactured locomotives;

e) adhesion (traction);

f) AC traction;

g) radio controlled remote locomotive consists; and

h) other locomotive components.

Virtually all the freight locomotives in North American service are produced by three manufacturers: the Canadian firm of Bombardier Inc., (formerly Montréal Locomotive Works), and the two American manufacturers, General Motors Electro-Motive Division and General Electric Diesel Division.

This chapter identifies three generations of locomotives starting with the first 1 500 h.p. units introduced in 1948 and followed by subsequent generations, as locomotives are replaced after some 15 years of service.

2.2 Locomotive Development Since 1945

The history of railroad motive power illustrates the way in which technological innovation can revolutionize a major industry. Steam motive power dominated the early ages of railroading in Canada beginning with the opening of a 16-mile line between St. Jean and Laprairie, Québec in 1836. At the

time of confederation in 1867 there were 2 500 miles of rail served by the steam locomotives of the Grand Trunk and Great Western Railways.

The first diesels to appear were 600 h.p. yard switching units introduced in 1938 by Canadian National Railways. At the time, these mechanical drive units were viewed as having only limited use. This changed, however, with the introduction of the diesel-electric units utilizing the diesel engine to drive a generator which in turn supplied electric power to traction motors at each axle of the locomotive.

In 1948 the first generation diesel-electric units, 1 500 h.p. locomotives built by General Motors, appeared in North American road service. This event signalled the beginning of the end for steam traction. From 1948 to 1962 some 5 000 steam locomotives disappeared from service having been replaced by 3 000 diesel-electric units (see Figure 2.1). In 1978, Canada's rail traffic was handled by 4 057 diesel units [2]. Over the same period of time, output, measured in ton-miles of revenue freight, increased from 58 billion in 1948 to 137 billion in 1978 [3,4,5].

The speed with which this revolution took place was assured by the fact that the investment required to produce diesels would be rapidly repaid by fuel savings alone, due to the improved efficiency of the diesel cycle. In terms of thermal efficiency, the diesel locomotive used fuel about six times more efficiently than existing steam power. Other benefits, including reduced locomotive maintenance, the elimination of steam locomotive servicing facilities, and reduced rail head wear had not been anticipated, but proved even more beneficial as the conversion progressed.

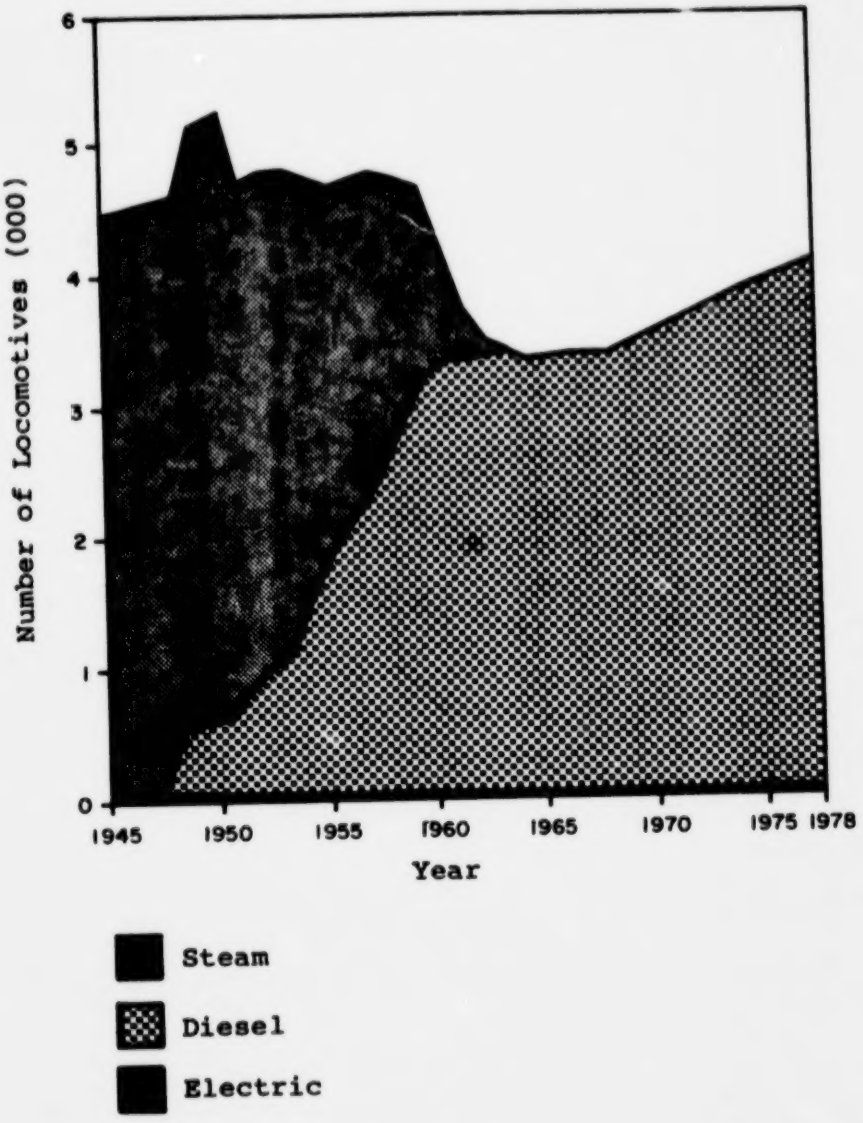
Not all of the impacts associated with diesel conversion were beneficial. Employees whose duties included water servicing, locomotive maintenance, and manufacturing found that their skills were no longer needed. On board the locomotives, the three-man crew (engineer, fireman and brakeman) were initially maintained [1]. However, through joint management/union co-operation the fireman's role, now redundant, was gradually eliminated through attrition.

Without frequent fuel and water stops, diesel locomotives were capable of running much further than their steam counterparts. Crew pay for many years, however, was still based on an eight hour or a one hundred-mile day. Such institutional problems as these, meant that many of the potential cost savings resulting from the conversion were never realized as additional railway profits or higher employee wages.

The first generation of mainline diesels used engines of 1 500 to 1 750 h.p., the most powerful available then [6]. As railroads found it economically desirable to handle longer

Figure 2.1

NUMBER OF LOCOMOTIVES IN CANADIAN SERVICE
BY MOTIVE POWER 1942-1978



Source: [3] Diesel yard switchers first introduced in 1938 followed by the first diesel-electric road unit in 1948. Their use increased steadily until the last steam locomotives disappeared from service in 1962.

and heavier trains, it became necessary to use several of these locomotives to pull the heavier loads.

Obviously, important economies could be realized if these multiple small locomotives could be replaced by a fewer number of larger units. The technical key opening the door to this advance was the exhaust gas driven turbo-charger developed in the mid-fifties. This device introduced in 1959 was simply a blower driven by the momentum of escaping exhaust gas. It supplied additional air to the engine under pressure, thereby increasing the engine's power. Turbo-charging, along with other refinements, permitted the maximum power of the engine to be more than doubled. This made possible the "second generation" of diesels rated in the 3 000 h.p. range. They were introduced as the first generation units began falling due for replacement starting in 1960. Since then, the business of the diesel locomotive industry for the last 20 years has been to replace the "first generation" of diesels. Often one new unit replaced two first generation units. More recently the increase in interest rates and labour costs has led to extensive remanufacturing of older units bringing them up to modern specifications at a cost of 20% to 50% of a new unit at today's prices.

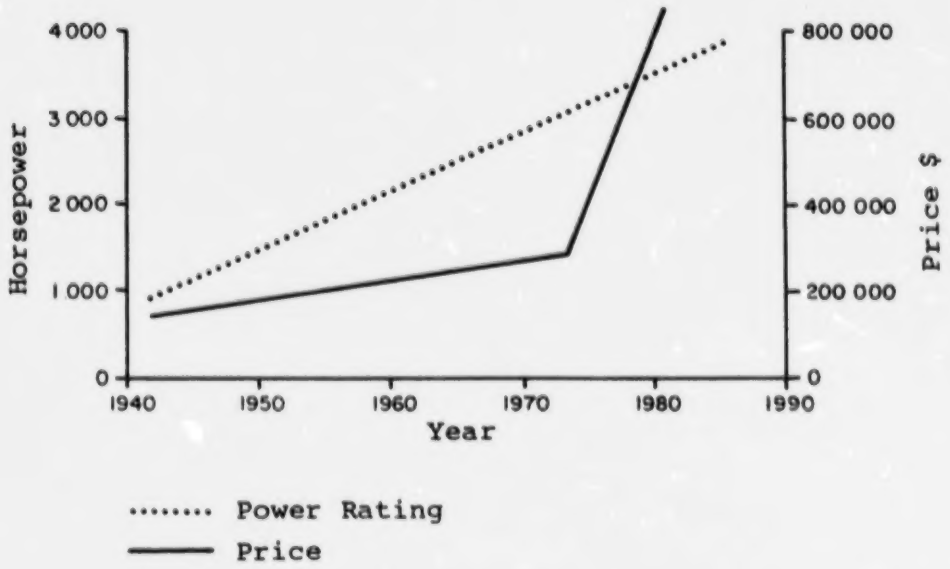
With the introduction of the second generation diesels, the locomotive fleet size has increased only 26% since 1960 while the work done, measured in ton-miles, has increased 128% over this same period [3,4,5].

The third generation locomotive units now being delivered are a further evolution of the original diesel-electrics. Most notable among the features of the third generation units are: reduced fuel consumption while maintaining or actually increasing power output, and extensive use of micro-processors to control locomotive operation and track adhesion. These units are now rated at 3 500 h.p. but there is nothing in view to repeat the quantum leap in performance made possible by the development of the exhaust gas turbo-charger introduced with second generation units. The possible exception to this is the bottom cycle turbine (see section 2.3) which utilizes waste exhaust heat energy to augment drive-line power.

Changes in power rating and price over time are shown in Figure 2.2.

Figure 2.2

DIESEL-ELECTRIC LOCOMOTIVE POWER AND PRICE INCREASES



Sources: [7, 8, 9]

For many years the cost of diesel-electric locomotives remained relatively constant in the range of $100 per h.p. (with locomotive purchases being financed at interest rates of 3% or less). Prices over the last eight years have increased dramatically to $330 per h.p. The sharp increase is due primarily to the high cost of capital and labour. Recent orders for new locomotives by Sante Fe and Union Pacific totalled 340 new units at an average cost of $800 000 (U.S.) each. In Canada current orders by Canadian Pacific Railway for 160 new units average $950 000 (CDN) each [10].

Over an extended period of usage, the diesel-electric locomotive has been reduced to two main types. The CoCo (two three-axle trucks) type locomotive illustrated in Figure 2.3, is used for large trains or in heavy grade territory where adhesion requirements supplant horsepower. For higher speed operation over flat country, the four-axle Bo-Bo locomotive (see Figure 2.4) will continue to dominate. The general layout diagrams show the major components of a typical North American freight locomotive. The major drive components of the locomotive are: the diesel engine, main alternator or generator, and the traction motors.

In recent years the majority of locomotive orders have been for the six-axle locomotives reflecting a move to heavier, longer trains (see Figure 2.5). This trend however is now

expected to diminish in favour of expanded use of four-axle locomotives. There will always be applications for heavier six-axle units, but their use will be limited to situations where they are absolutely necessary. The increasing price difference between a six-axle over a four-axle unit and fuel costs of hauling an extra 50 to 60 tons per locomotive will favour technological development of four-axle locomotives for more applications [11].

The range of diesel-electric locomotives currently available, or soon to be released in North America, are presented in Table 2.1. These new locomotives, with their first deliveries in 1980 and 1981, are representative of the types of locomotives which will make up the bulk of railroad fleets over the next 15 years. General Motors, for example, began producing new four-axle GP-50 units in April 1980 and the six-axle SD-50 version is scheduled for production in 1981.

Design features of the latest third generation production locomotives by all three manufacturers emphasize several common areas of development including:

a) emphasis on fuel economy improvements making them about 7% better than previous models;

b) modular design of electrical and other locomotive components to permit quick replacement;

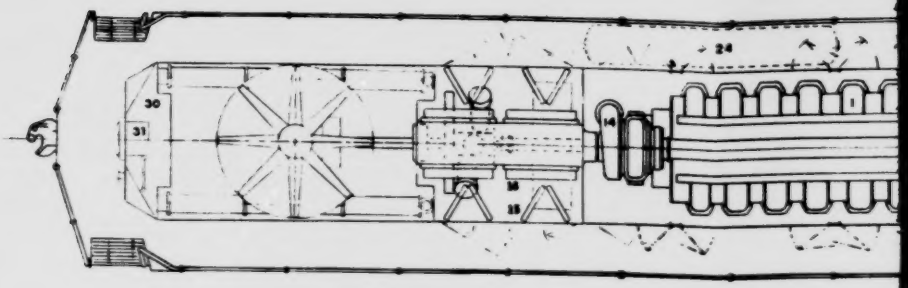
c) modern slippage control systems, increasing by 33% a locomotive's ability to pull up steep grades; and

d) introduction of micro-processors to assist locomotive control and operation.

In Canada, Bombardier Inc., has been contracted by the Department of Industry, Trade and Commerce to develop a prototype of what may be the first truly new generation of locomotives. The prototype will be redesigned from the ground up bringing together all of the latest locomotive technologies as a system rather than retrofitting current production designs. The new locomotive may include such technologies as AC traction motors (section 2.8), steering axle trucks (section 5.4), and micro-processors for control and operation.

2.3 Prime Movers

The prime mover is the source of power used to drive the locomotive. In the case of diesel-electric locomotives, the prime mover is on-board in the form of the diesel engine. Electric locomotives however have no on-board prime mover. Power is supplied from an external source via an overhead catenary system. In this case, the locomotive acts only as a power conditioner regulating the power supplied to the traction motors. It does not generate its own power supply.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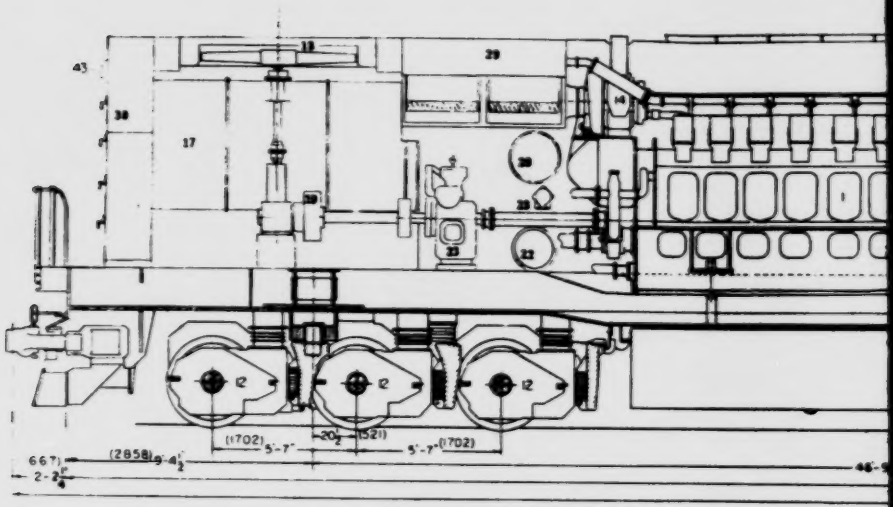
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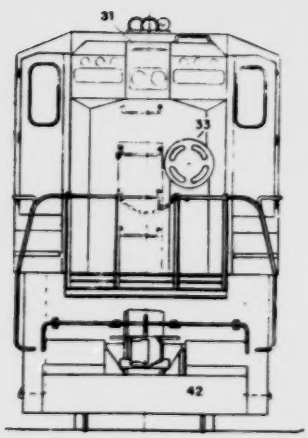
18
29
38
17
14
28
25
23
12
12
12
(1702)
5'-7"
20½
(521)
5'-7"
(1702)
667
(2858)
9'-4½"
2-2¾"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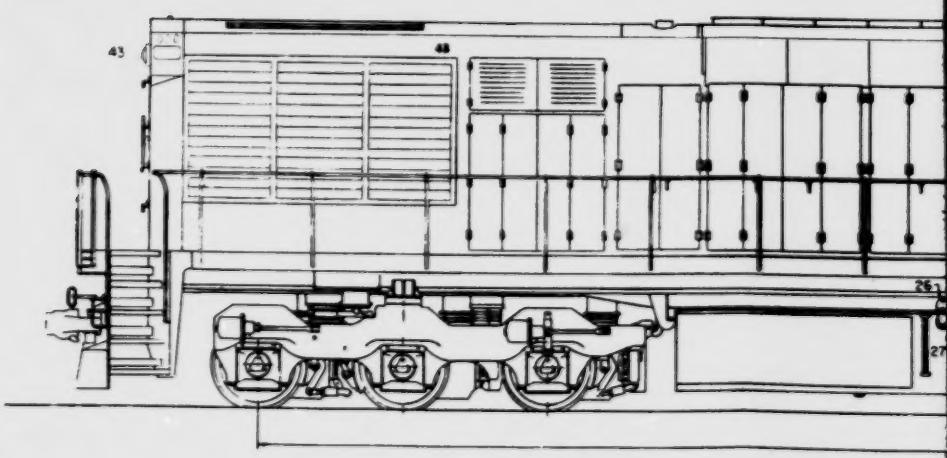
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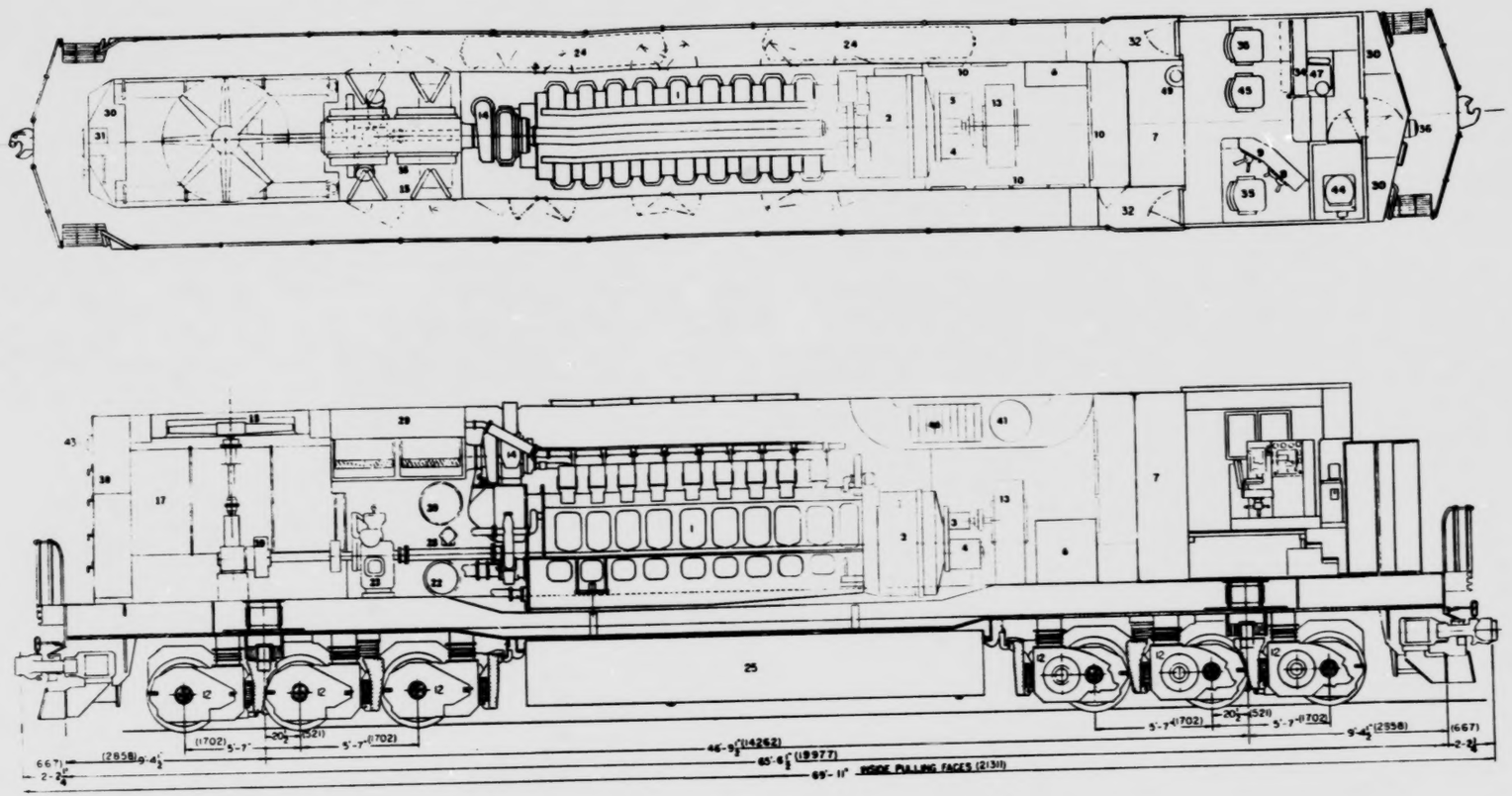
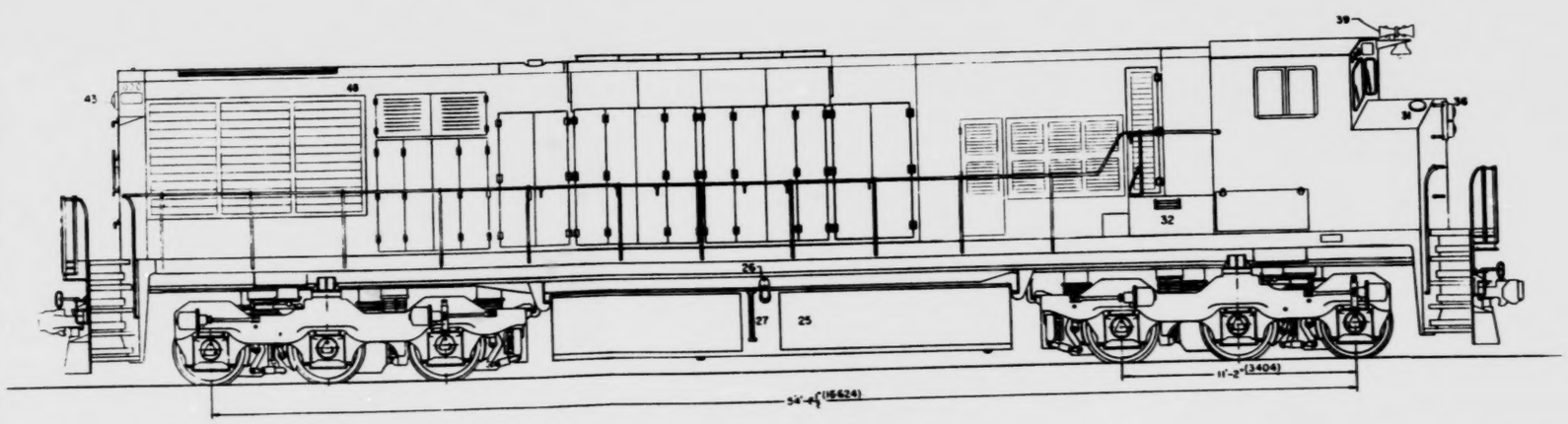




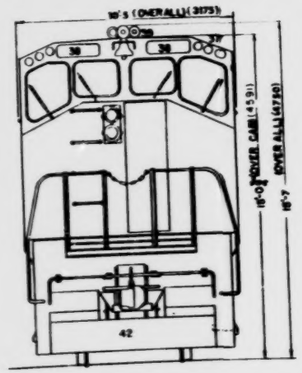


Figure 2.3

GENERAL ARRANGEMENT OF A SIX-AXLE FREIGHT LOCOMOTIVE

1. Engine
2. Main generator
3. Gear unit-blower drive
4. Auxiliary generator
5. Exciter
6. Rectifiers
7. Control compartment
8. Control stand
9. Brake valves
10. Carbody filter
11.
12. Traction motor
13. Blower-traction motor
14. Turbocharger
15. Engine air intake filters-primary
16. Engine air intake filters-secondary
17. Radiator
18. Radiator fan
19. Radiator fan clutch
20. Lubricating oil filter
21.
22. Lubricating oil cooler
23. Air compressor
24. Main air reservoir
25. Fuel tank
26. Fuel tank filling connection
27. Fuel tank gauge
28. Fuel oil filter
29. Engine water expansion tank
30. Sand box
31. Sand box fill
32. Batteries
33. Hand brake
34. Cab heater
35. Cab seat
36. Headlight
37. Classification light
38. Number box
39. Horn
40. Bell
* 41. Dynamic brake blower
42. Pilot
43. Back-up light
44. Toilet
45. Cab seat
* 46. Dynamic brake resistors
* 47. Water cooler
48. Radiator shutter
* 49. Hot plate

*Modifications

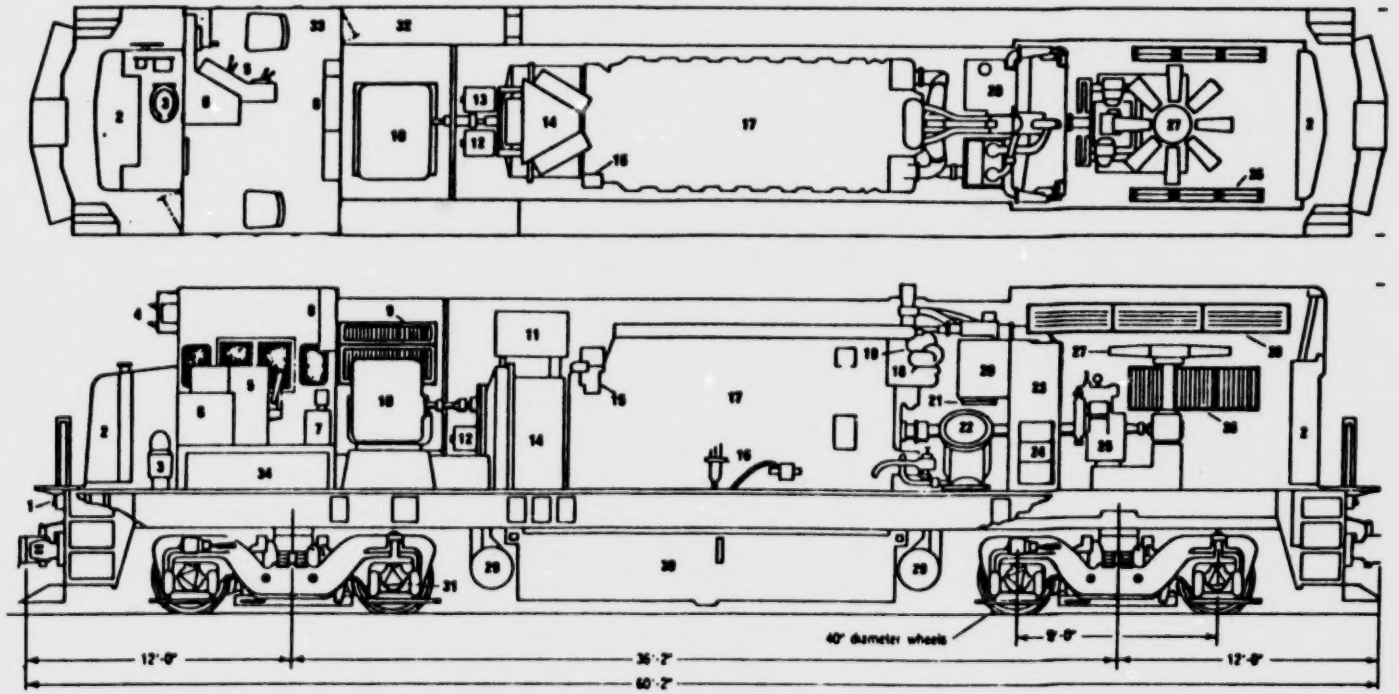
Bombardier Inc

9838-090423

Source: [12]

Figure 2.4

GENERAL ARRANGEMENT OF A FOUR-AXLE
FREIGHT LOCOMOTIVE

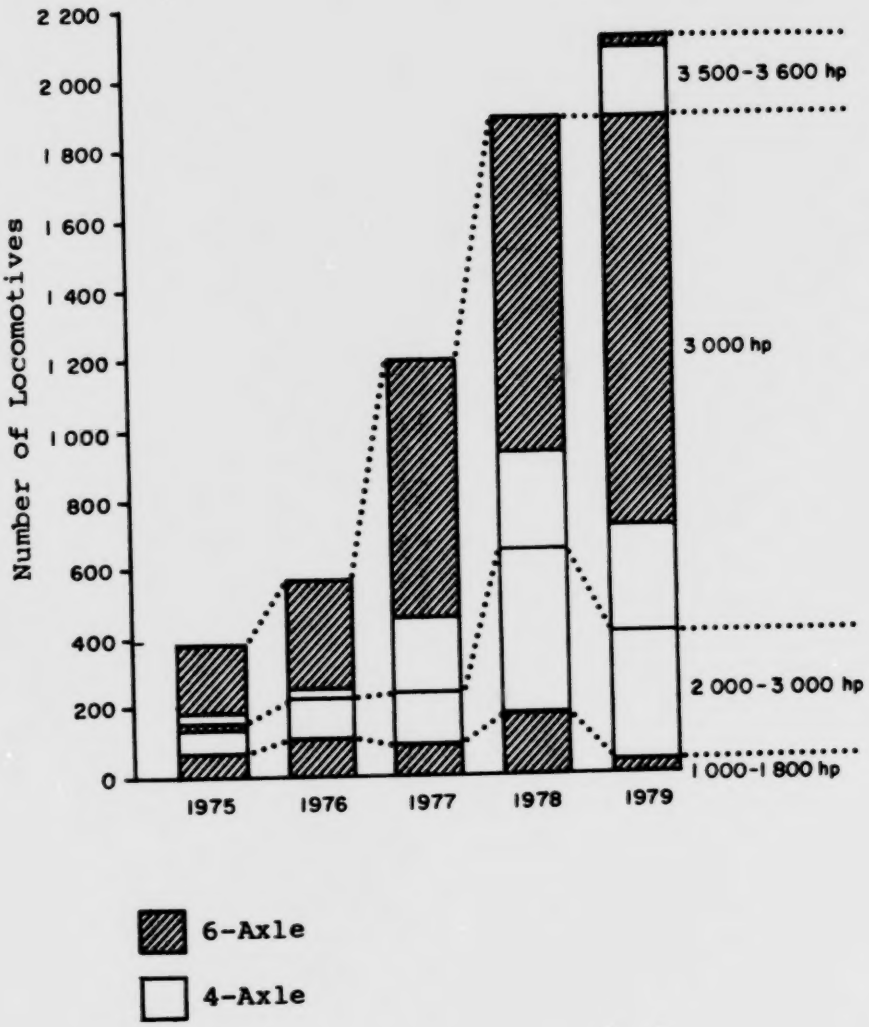


1. Multiple-unit connectors
2. Sand box
3. Toilet (when furnished)
4. Headlight and number boxes
5. Operating controls
6. Cab heater
7. Water cooler (when furnished)
8. Engine control panel
9. Equipment air intake
10. Equipment blower
11. Rectifier
12. Auxiliary generator
13. Exciter
14. Traction generator
15. Governor
16. Fuel oil transfer pump and filter
17. Diesel engine
18. Intercooler
19. Turborcharger
20. Cooling water storage tank
21. Lube oil cooler
22. Lube oil filter
23. Oil bath air filters
24. Engine primary air cleaners
25. Air compressor
26. Dynamic brake grids (when furnished)
27. Radiator fan
28. Radiator
29. Air reservoir
30. Fuel tank
31. Axle alternator (one per axle)
32. Battery (right side)
33. Air brake equipment (right side)
34. Control equipment compartment (left side)

TODAY'S standard locomotive is a hood type road-switcher. This is a low-nose GE U36B--3600 h.p., four axles, all powered.

Figure 2.5

LOCOMOTIVES ORDERED FOR
NORTH AMERICAN SERVICE 1975-1979



Source: [11]

Table 2.1

CURRENT ROAD FREIGHT LOCOMOTIVES FOR NORTH AMERICAN SERVICE

Locomotive Model			Wheel Arrangement	Engine					Locomotive wgt. (Service, lb)		Standard Features	Examples of available Optional Items	Notes
Bombardier Inc.	Electro-motive	General Electric		hp for traction	Cylinders	Full Load rmp	Model	Turbo-Charger	Minimum	Maximum			
	GP-15-1		B-B	1 500	12	900	645E	No	240 000			Low Idle	Available on trade-in only
		B-18-17	B-B	1 800	8	1 050	FDL	Yes	230 600	268 000	83:20 gearing	Low Idle	
	GP-38-2		B-B	2 000	16	900	645E	No	250 000	277 500		Low Idle	SD-39 6-axle equivalent available
		B-23-7	B-B	2 250	12	1 050	FDL	Yes	253 000	280 000		Low Idle	C-23 6-axle equivalent available
	GP-39-2		B-B	2 300	12	900	645 E3B	Yes	250 000	277 500		Low Idle	
HR412			B-B	2 400	12	1 000	251E	Yes	240 000	272 000	Micro-limit slip	500 kw head-end power full-width carbody	First Deliveries 1981
	GP-39X		B-B	2 700	12	950	645F3	Yes	N/A	N/A	Super-Series Wheel creep control 70:17 gearing		GP-49 prototypes delivery late 1980
		B-28-7	B-B	2 750	12	1 050	FDL	Yes	253 000	280 000	83:20 gearing	Low Idle	
		C-28-7	C-C	2 750	12	1 050	FDL	Yes	359 000	420 000	83:20 gearing	Low Idle	
	GP-40-2		B-B	3 000	16	900	645 E3B	Yes	256 000	277 500		Low Idle	
		B-30-7	C-C	3 000	16	1 050	FDL	Yes	259 000	280 000	83:20 gearing	752 AF motors Low Idle	
	SD-40-2		C-C	3 000	16	900	645 E3B	Yes	368 000	420 000		Low Idle	
		C-30-7	C-C	3 000	16	1 050	FDL	Yes	366 000	420 000	83:20 gearing	752 AF motors Low Idle	

Locomotive Model			Wheel Arrangement	Engine					Locomotive wgt. (Service, lb)		Standard Features	Examples of available Optional Items	Notes
Bombardier Inc.	Electro-motive	General Electric		hp for traction	Cylinders	Full Load rmp	Model	Turbo-Charger	Minimum	Maximum			
HR416			B-B	3 200	16	1 000	251E	Yes	255 000	280 000	Micro-limit slip detection	500 kw head-end power full-width carbody	First Deliveries 1981
HR616			C-C	3 200	16	1 000	251E	Yes	380 000	420 000	Micro-limit slip detection	Full-width carbody	First Deliveries 1982
	GP-50		B-B	3 500	16	950	645F3	Yes	260 000	277 500	Super-Series Creep control 70:17 gearing		First Production-unit deliveries in April 1980
	SD-50		C-C	3 500	16	950	645F3	Yes	368 000	N/A	Super-Series wheel creep control 70:17 gearing		First Deliveries 1981
		B-36-7	B-B	3 600	16	1 050	FDL	Yes	260 000	280 000	Sentry Adhesion Control 83:20 gearing	Low Idle	First Deliveries in October 1980
		C-36-7	C-C	3 600	16	1 050	FDL	Yes	366 000	420 000	Sentry Adhesion Control 83:20 gearing	Low Idle	
HR618			C-C	3 600	18	1 000	251E	Yes	388 000	420 000	Micro-limit slip detection	Full-width Carbody	First Deliveries 1982

This section deals with recent advances made in the development of on-board prime movers. The diesel engine will continue to fill this role over the next ten years although the types of fuel used may vary. Ongoing research continues in alternative engines, but a unit able to compete with the well developed diesel in first cost, fuel economy, and reliability has not yet been developed. This situation may be altered by the availability and relative cost of various fuels or by policy decisions favouring electrification.

The first generation of diesels used naturally aspirated engines rated at 1 500 h.p. These engines began being replaced by a second generation of diesel locomotives some 15 years later as the first generation came due for their third major overhaul. The second generation locomotives were 3 000 h.p. units incorporating the exhaust driven turbo-charger. The turbo-charger simply uses the momentum of the engine's exhaust gases to drive an air pump which in turn feeds air into the engine under pressure at up to 16 psi [13]. This increases the engine's thermal efficiency and power output.

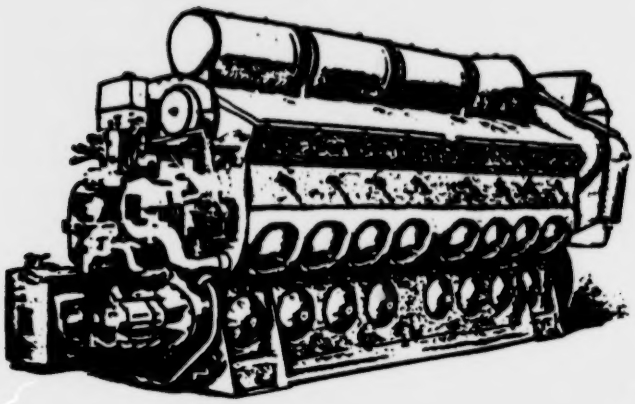
As the second generation units are now reaching the end of their economic life, they are currently being replaced by a third generation of locomotives. The third generation diesel units are basically a refined version evolving from the second generation turbo-charged diesels. Power available for traction has been increased on some models, but the emphasis in design has been on fuel economy (see section 2.4).

Over the past few years technological development has shifted from increasing power to producing a conservative, more reliable product that is cheaper to maintain in terms of its life cycle cost [9,11].

General Motors' state-of-the-art diesel engine, the Model 645F pictured in Figure 2.6, delivers 500 more horsepower than its predecessor, while at the same time reducing fuel consumption by 3.5% (about 11 000 gallons, per year). The engine improvements discussed more fully in section 2.4 include: improved fuel injection, engine bearing design, turbo-charger operation, reduced throttle settings in dynamic braking and at idle, and engine "purge control" allowing operators to shut the engine off when not in use.

Figure 2.6

EMD MODEL 645F DIESEL



EMD's 16-cylinder 2-stroke turbo-charged 645F diesel used in the new series 50 locomotives. It delivers 3 800 h.p. of which 3 500 h.p. is available for tractive effort.

Bombardier Inc., which has been building locomotives since 1904, manufactured its first production diesel locomotive in 1948. Since then it has produced over 2 500 units, 30% of which were shipped to overseas customers. Its current engine designs include 6, 8, 12, 16 and 18-cylinder models ranging from 875 to 4 500 b.h.p. These engines are manufactured under licence from the American Locomotive Company (ALCO). These new locomotives are scheduled for release in 1982. They incorporate cooling fans, engine and turbo-charger improvements resulting in a 7.1% decrease in fuel consumption with the same power output. Engine maintenance and reliability will be enhanced by on-board micro-processor diagnostic equipment for identifying faults or malfunctions [14].

General Electric is also planning more fuel saving measures in 1981 in a new version of its 16-cylinder, 4-stroke engine. It is claiming fuel savings of 7% with modifications similar to those made by General Motors [15].

Despite the fact that the diesel engine seems to be peaking out in performance, it should remain the dominant form of prime mover for locomotives for the next eight to ten years. The thermal efficiency of a modern diesel, now about 30%, is difficult to improve without increasing thermal loading. Power increases would mean trading off engine efficiency for higher maintenance costs and reduced reliability. Any future power increases must therefore be accompanied by improved reliability. At the very least, there should be no loss in reliability, as any economic gains from fuel savings will be

rapidly lost by a locomotive taken out of service for repairs. In addition to maintaining reliability, performance improvements must now be accomplished without increasing gaseous emissions [16].

Alternate engines for locomotive prime movers such as: gas turbines, steam engines, Stirling engines, free piston engines and even nuclear engines have been considered or developed. None of these, however appear able to compete with the diesel. The average life of a diesel-electric locomotive is 15 to 20 years, after which time the locomotive may be sold or remanufactured to modern diesel standards. The long life and proven reliability of current hardware makes it difficult for new, unproven technologies to enter the market. Nevertheless the railroads over the last ten years have shown an increased willingness to accept new technology given the capital to implement it. The direction which future freight locomotive design takes will be influenced by past operating experiences leading to the development of an evolutionary product.

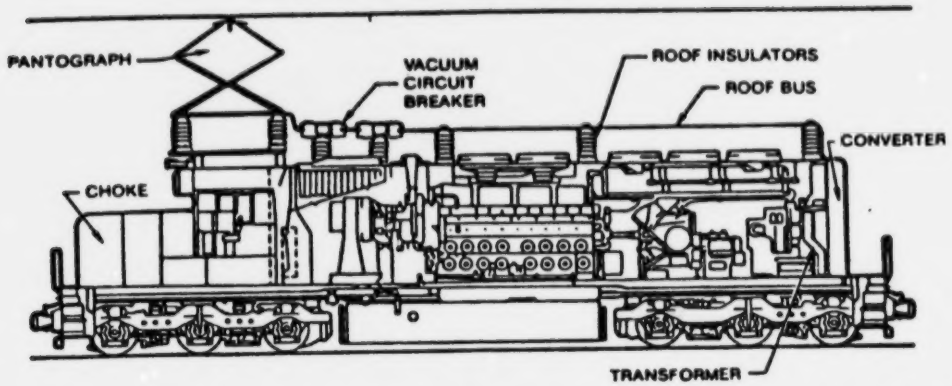
In the past the most serious contender to the diesel has been the regenerative cycle gas turbine [6]. From 1947 to 1949 Union Pacific Railroad had 55 gas turbine-electric locomotives in service [17]. These locomotives rated up to 8 500 h.p. were built jointly by General Electric and ALCO. Although they were a technical success at the time and served well in heavy freight drag operations, they gradually disappeared from service. The engines were fixed blade turbines with a very narrow efficient operating range. For low speed operation, an auxiliary diesel engine was needed to power the locomotive in order to avoid high fuel consumption and to prevent ash build-up in the turbines while at idle or low speed. The use of other fuels such as propane or coal dust were also experimented with but were generally not considered feasible, as they required new servicing facilities for the second type of fuel.

Today, the turbine as a prime mover still lags behind the diesel in fuel economy and first cost, both are important in a railroad locomotive. On the other hand, the turbine's advantages of reduced weight and compactness are not very significant in railroad applications. However, the turbine's ability to burn a variety of fuels may in future be an important factor if diesel fuel supplies become scarce.

Recently some interest has been shown in developing a dual mode locomotive as an alternative to full electrification of main lines. Figure 2.7 below shows such an arrangement.

Figure 2.7

DUAL-MODE LOCOMOTIVE



The projected Dual-Mode Locomotive. Drawing power from a high-voltage catenary on a steep upgrade (and feeding power back on the downgrade), it would deliver about 50% more horsepower than when operating as a diesel-electric.

Source:[11]

At present the U.S. Federal Railroad Administration (FRA) and the Department of Energy are proposing to the railroads, a six-year program to build and evaluate a dual-mode locomotive. The FRA estimates it is possible to recover capital costs in three years with the new system, as opposed to a recovery time of six to ten years for conventional electrification, by electrifying only those sections of the line with the highest energy requirements.

In the event that mainline electrification is implemented, the dual-mode locomotive could also operate on lower volume non-electrified branch lines and sidings.

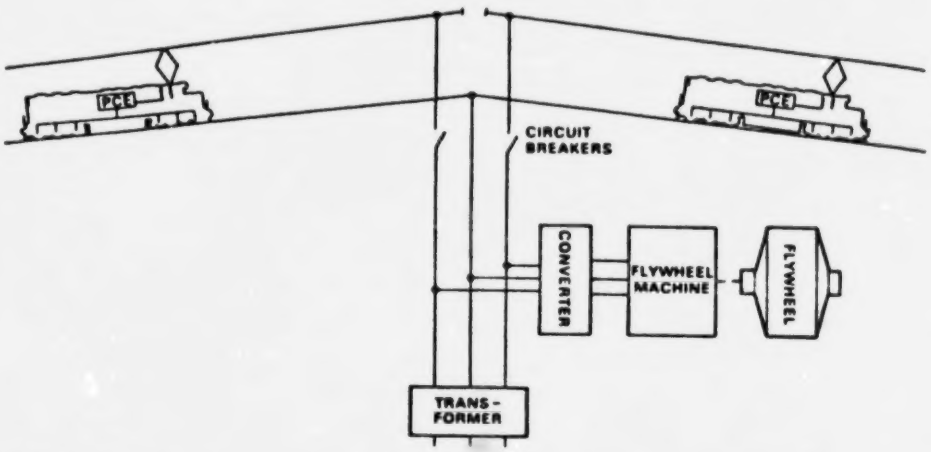
In the future, electrifying sections of rail where steep grades are encountered will allow heavy trains to recover through regenerative braking, some of the energy now wasted by dynamic and friction braking. In this mode of operation, traction motors are made to act as generators returning power to the overhead catenary, while braking the train on a downgrade. In this manner significant power can be recovered.

For example, in the one hour it takes a large freight train to descend the Cajon Pass near San Bernadino, California, enough electrical energy can be generated to supply a residential community of 30 000 persons. Based on 1977 fuel costs this would amount to $500 in savings of diesel fuel in one hour.

Studies have also been carried out to examine the feasibility of Wayside Energy Storage Systems, [18,19] as illustrated in Figure 2.8 below. Using this technology, energy produced by a train through regenerative braking on a downgrade is stored in a 604 ton flywheel in a pit alongside the track. The stored energy is then used by the next train ascending the grade.

Figure 2.8

WAYSIDE ENERGY STORAGE SYSTEM (WESS)



The WESS system is compatible with standard mainline electrification, minimizes hardware requirements, minimizes the effect of intermittent heavy power loads on utilities and allows power regeneration on the downgrade.

The feasibility of using an on-board flywheel storage system for yard-switching locomotives has also been examined [21]. Data collected from actual yard switcher duty cycles was used in a computer model to simulate operation with and without the flywheel. The study showed that no fuel savings resulted due to the added weight of a separate box car needed to house the flywheel system. On-board flywheel storage systems for larger mainline locomotives are not yet practical due to the large size of the system required. Research is now being carried out to prove the feasibility of an alternate prime mover derived from technology of the steam era.

A modern version of the coal burning reciprocating steam engine is being proposed by American Coal Enterprises [22] with private backing for the project. It is estimated that the first two prototypes will cost $25 million to build; production models could be constructed at a cost approximately 25% over that of current diesels. At current fuel costs, the coal fired

locomotive is estimated to reduce fuel costs by 33% relative to its diesel counterpart. The coal fired locomotive has a thermal efficiency of 15%. This is a three-fold increase over earlier steam locomotives, but still not more than half of today's diesel locomotives.

The proposed steam locomotive would have four 60 000 lb. drive axles powered by four steam cylinders driving large 54" wheels. It is being designed to travel 500 miles between fuel stops and 1 000 miles between water stops. The stoker, air flow, boiler feed and other locomotive functions will all utilize modern micro-processor controls.

No estimates of the costs of wayside fuel and water servicing were available.

Other advanced propulsion systems for use as railroad prime movers are being studied by private organizations under sponsorship of the United States Federal Railroad Administration. Investigations include such technologies as bottoming cycles, turbo-compounding, adiabatic diesels, Stirling Cycle Engines, Rankine Cycle Engines and Brayton engines. Results of these experiments will be available at the end of 1981 [20].

Engines using alternate fuels such as alcohol, hydrogen or off-specification diesel fuel are discussed more fully in Chapter 3.

2.4 Fuel Efficiency

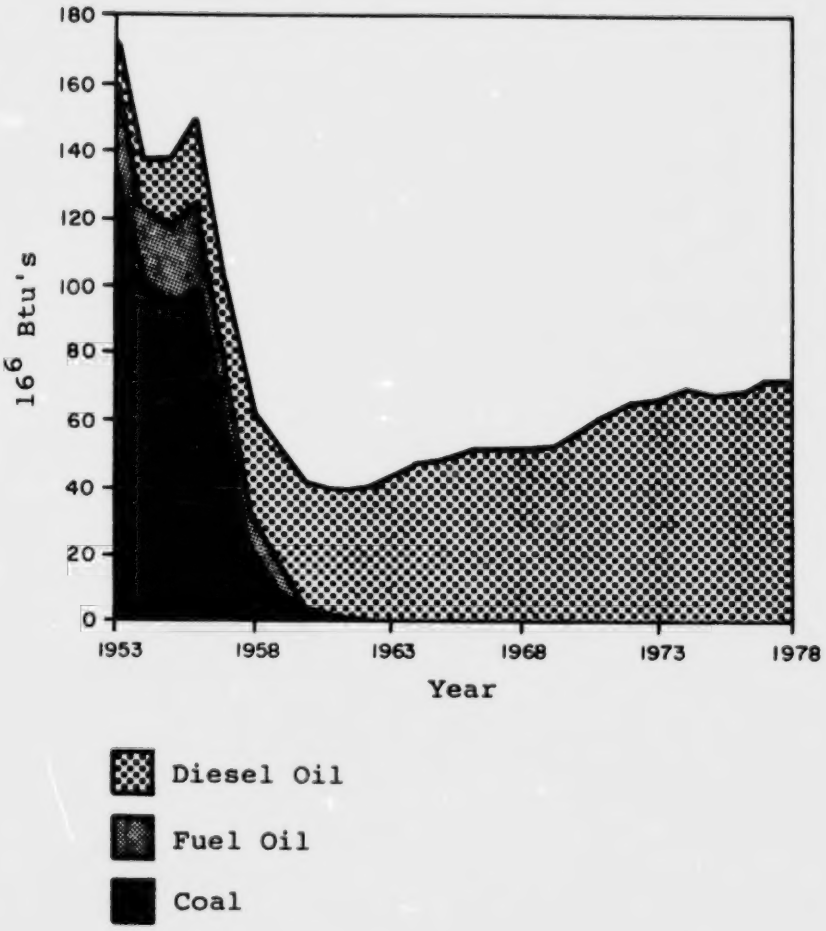
The best coal burning locomotives of the steam era achieved a thermal efficiency of 4% to 5% in converting the heat energy of coal to useable mechanical energy. With conversion to diesel power and 30% efficiency, there was a large decrease in energy consumption. The energy used today by locomotives is still less than half the amount consumed by team locomotives in 1953. This is illustrated in Figure 2.9.

With the abundance of diesel fuel, the emphasis in diesel design from 1948 to 1973 was placed on increasing power output. During this time few improvements were made in fuel efficiency. The impact of rising fuel costs since 1973 shifted the emphasis in design away from higher power outputs towards improved fuel economy.

Turbo-charging modern diesels has improved fuel consumption to .365 lbs. per h.p./hr., compared to .390 lbs. per h.p./hr., for previously naturally aspirated engines [13]. Fuel consumption for mainline locomotives is now about 1.33 imperial gallons per mile.

Figure 2.9

ENERGY CONSUMED BY MOTIVE POWER-
FREIGHT SERVICE IN CANADA 1953-1978



Source: [2]

Fuel costs have risen dramatically despite improved efficiency. In 1968, the average annual fuel costs were $17 000 per unit compared to $65 000 per unit in 1978 [2]. Presently, some 4 000 diesel-electric locomotives annually consume 500 million gallons of fuel or 17% of the diesel fuel consumption in Canada.

Table 2.2, which follows, shows fuel consumption rates and percentage time at various throttle settings for a typical second generation freight locomotive. Idling time accounts for a high percentage of operating time. It has been normal practice to keep an engine running continuously between overhauls. Engine purge controls described later will allow newer engines to be shut down when not in use.

For estimating fuel consumption, annual operating time is roughly 6 700 hours for a mainline locomotive. Since full throttle and idle account for up to 71% of the operating time, improvements in these areas will significantly effect overall consumption.

Improving the efficiency of the actual diesel cycle is difficult but many changes are being made to locomotive auxiliary equipment and its operation to reduce fuel consumption.

In their new model 645F engine, General Motors has increased power available for traction from 3 000 to 3 500 h.p. while reducing fuel consumption by 3.5% or roughly 11 000 gallons, per year.

Some of the fuel saving modifications made to this third generation engine are: [25,95]

a) improved fuel injection resulting in a 2% improvement in fuel consumption at maximum rated power;

b) a new "rocking pin" bearing design for the piston wrist pins to improve lubrication to offset the increased engine loading;

c) at low engine speeds the turbo-charger is mechanically assisted resulting in a 1.5% fuel economy improvement over typical duty cycles;

d) thermostatically controlled radiator fans which operate only when required;

e) a lower throttle setting for dynamic engine braking resulting in a further 1% fuel saving in this mode of operation;

f) better engine thermal efficiency as a result of an improved injection system;

Table 2.2

TYPICAL FUEL CONSUMPTION AND DUTY CYCLES FOR
A FOUR-AXLE GENERAL PURPOSE DIESEL-ELECTRIC LOCOMOTIVE

Throttle Position	Fuel Consumption Rate GP-40 Loco (imp. gal./ hr)	Rated Power %	Duty Cycle		
			Heavy	Medium	Light
8	140	100	30	17	9
7	121	86	3	4	3
6	90	66	3	4	3
5	66	51	3	4	3
4	48	35	3	4	3
3	34	23	3	4	3
2	21	12	3	4	3
1	6	5	3	4	3
Idle	5	0.75*	41	46	66
Dyn. Brake	17	3	8	9	5

* Locomotive Auxiliary Power

Sources: [23,24]

g) idling speed reduced from 316 to 255 rpm resulting in a 7% fuel saving over typical duty cycles; and

h) automatic engine purge control which allows engines to be shut off when not in use and restarted without the possibility of engine damage due to coolant leaking into the cylinders. In the past normal practice has been to leave an engine running continuously between overhauls. With purge control, an engine may be shut down when the ambient temperature is over 10° C. Fuel savings become significant in light of the fact that in typical duty cycles an engine spends 40% of its time idling. As no suitable locomotive antifreeze solutions have yet been developed, engines are never shut down when temperatures are below freezing [13]. Conventional glycol based

solutions, should they leak into the engine, oil would cause rapid engine failure which the operators are not willing to risk.

Bombardier Inc., claims fuel economy improvements of 7.1% or about 23 000 gallons per year over previous models, while maintaining the same power rating [14]. These improvements include:

a) redesigned engine and turbo-charger components;

b) thermostatically controlled cooling fans; and

c) reduction in engine speed at full throttle from 1 100 to 1 000 rpm.

Fuel economy improvements made by General Electric to their new locomotives are claimed to reduce fuel consumption by 7.2% or roughly 23 000 gallons per year. These improvements include:

a) turbo-charger improvements;

b) reduced cooling fan horsepower through thermostatic control;

c) lower engine idle speed; and

d) better matching of engine speed to load and dynamic braking requirements.

Further fuel economies may be realized by add-on devices not yet widely used and by modifying locomotive operating policies.

Reducing train speed will reduce fuel consumption since aerodynamic and rolling resistances and hence horsepower requirements are a function of speed. Lower train speeds must be achieved by lowering the number of engine units or increasing train tonnage. The engine throttle setting should not be lowered since fuel consumption characteristics of turbo-charged diesels are such that specific fuel consumption, measured in gallons per rail horsepower, increases at lower throttle settings [11].

If train speed can be maintained by full throttle operation of some of the units of a train having more than one locomotive (multi-unit consist) while the remaining engines are at idle, then there will be a potential fuel saving. The "fuel-saver" device tested by the United States Federal Railroad Administration allows the engineman in the lead unit to control trailing units individually. The control unit cost, $1 100 (U.S.), is said by several railways, to produce up to 10% reductions in fuel consumption depending on the terrain [26].

CP Rail research claims that full throttle operation has an efficiency advantage over intermediate throttle settings of 5% at most and the fuel consumption of the engine at idle is from 4% to 7% of full throttle operation. Thus they conclude that the best fuel saving one can expect is 1% [27]. CP feels that savings claimed by other users are the result of reduced running speeds which in turn reduce the horsepower requirements.

As the price of fuel escalates, the efforts to reduce locomotive fuel consumption will continue. Improvements in the near future will come in the form of: retrofit devices to current production locomotives, improved wheel/rail adhesion control, more careful control of railroad operations, slower trains, closer matching of power to load (particularly through the use of real-time micro-processors), education of railroad personnel in fuel-saving practices and improved locomotive maintenance.

Computerized train performance models are being developed to deal with fuel consumption and train resistance (rolling and aerodynamic) as a function of the individual cars rather than for the train as a whole [28]. Investigations show that fuel savings from various technologies are highly dependent upon the type of operation being run (speed, locomotive assignment, train handling, maintenance).

Increasing use of high adhesion four-axle locomotives in the future is also likely. A four-axle locomotive uses roughly 80 000 gallons less fuel per year in applications where it can effectively replace the six-axle units [32].

Possible areas for long term improvements in fuel efficiency include: power storage systems for regenerative braking on downgrades, reduction of aerodynamic drag and rolling resistance and improvements in the overall thermal efficiency of the diesel engine.

One possibility for improving thermal efficiency is to capture waste engine and exhaust heat energy using a Rankine Cycle Engine to augment drive-train power. Research into this process, known as bottom-cycling, is being carried out by the Thermo-Electron Corporation in Waltham, Mass. and by General Motors. An exhaust gas heat exchanger is used to heat a working gas which in turn drives a small Rankine Cycle Turbine adding 50 h.p. to a 288 h.p. diesel test engine in the Thermo-Electron laboratories [29]. If the same relative increase could be applied to a locomotive, engine power would increase from 3 500 h.p. to 4 100 h.p. without increasing fuel consumption. General Motors Electro-Motive Division has been researching this application for several years but as far as is known has not progressed past the laboratory stage.

Table 2.3 below shows potential for recapturing waste heat energy through such applications as the Rankine Cycle Engine. At present, 67% of the heat energy contained in a gallon of diesel fuel is lost as waste heat.

Table 2.3

DISTRIBUTION OF HEAT ENERGY
DERIVED FROM DIESEL FUEL

	Percent
Exhaust heat	31.0
Cooling water heat (dissipated at radiators)	19.0
Lubricating oil (heat)	7.0
Unaccounted for (mostly radiation off engine and machine friction)	9.5
Useful work	33.5
	100.0

Source: [30]

The "useful work" generated by the prime mover in addition to providing traction must also supply power for locomotive auxiliaries such as cooling fans, blowers, compressors and auxiliary generators. These may use 7% or 8% of the useful work available.

2.5 Maintenance and Reliability

Since many locomotive sales are financed under leasing agreements for tax reasons, the manufacturers, as well as the operators, are intimately involved in the economics of lower maintenance costs [9]. Manufacturers attempt to match a railway's economic needs with their products. The studies which now precede purchases include utilization as well as locomotive size and cost requirements. Current design philosophies have shifted the emphasis from higher power towards greater reliability, lower maintenance and increased fuel efficiency.

Class I railroads in the U.S. obtained 55% more net transportation per unit of material and labour expended in

motive power maintenance in 1979, than in 1969. In spite of this, however, maintenance costs have increased from an average of $28 000 (U.S.) per year per unit in 1969 to an estimated $73 000 (U.S.) per year per unit in 1979. These costs will vary widely depending on the individual railway and on operating conditions [11]. Figure 2.10 shows typical maintenance costs which might be used by a railway considering the purchase of two new 3 000 h.p. units to replace an old four-unit locomotive combination of the same total 6 000 h.p. (this presumes that operating conditions can be met with the lower axle load). Values are expressed in U.S. dollars per annum per locomotive consist, not per unit. The curves rise until they drop sharply at each major overhaul, resulting in a characteristic saw-tooth form with a basic rising trend.

Both for the railway user and for the manufacturer, emphasis in new locomotives is no longer on higher power but towards greater reliability, lower maintenance and fuel efficiency.

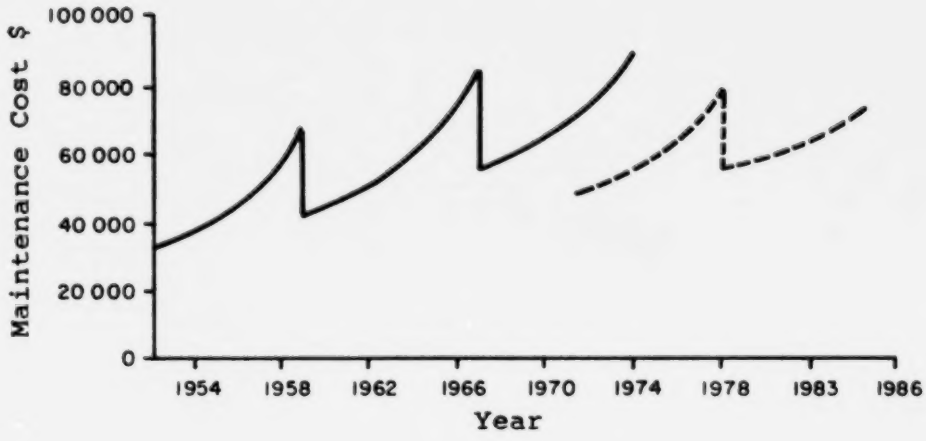
The major building blocks of a diesel electric locomotive (engine, generator, and traction motors) have undergone continuous development since 1936, so progress has been achieved by steady evolution. Each successive model has become more sophisticated, changing their requirements for maintenance. New models incorporate not only improved design features, but diagnostic equipment both on and off the locomotive to assist in identifying malfunctions.

One effect of increased fuel efficiency of locomotives which must be avoided is a loss of reliability due to the trade-off between the two. For example, a typical locomotive engine uses 360 000 gallons of fuel per year. At 80¢ per gallon, a 1% reduction in fuel consumption in a fleet of 100 locomotives would save $280 000. If this saving meant accepting a 1% reduction in locomotive availability, then one more locomotive at a cost of $1 million would have to be purchased. The net loss of $720 000 indicates the importance of reliability in locomotive design. This is one of the reasons why the industry is reluctant to accept innovative technology which lacks the proven reliability of existing units. In general, railroads seek a 90% availability for their locomotives [30].

Future development will be geared towards improved reliability, extended time between scheduled maintenance, and the reduction of down time by means of modular replacement capability. Rather than repairing a failed component on the locomotive, the future emphasis will be on quickly replacing the entire unit to return the locomotive to service. The use of on-board and wayside electronics in testing, fault finding and identifying malfunctions before they occur will increase. Routine maintenance procedures (such as wheel changeouts) will be increasingly automated over the next five years using technology now available from the automotive industry.

Figure 2.10

LOCOMOTIVE MAINTENANCE COSTS



Source: [9]

2.6 Remanufactured Locomotives

In the forties and fifties, purchases of new diesel-electric locomotives were financed at interest rates of 2.75%. With today's interest rates and mainline locomotives costing up to $1 000 000 or $750 000 for yard switchers [31], many railroads are finding it more economical to rebuild older locomotives rather than to purchase new units.

CP Rail are now upgrading their fleet and are faced with three options; either buying new locomotives, contracting out the work to rebuild locomotives, or doing the rebuilding themselves. They chose the third option. By rebuilding 400 of their own locomotives at an estimated cost of $48 million they can supply remanufactured units at a cost of approximately $120 000 each. The rebuilding process includes: straightening frames, rebuilding engines, wheel trucks, suspension, rewiring, improved operator comfort, and replacement of other locomotive equipment as required. This is part of a ten-year, $200 million program to upgrade their fleet of 1 300 locomotives. The program will also involve purchasing 83 mainline and 77 switching units between 1982 and 1986 at a cost of $152 million.

By 1990 the CP fleet "will be one of flexible four-axle reliability in switching service and six-axle power on the mainline" [10].

CN Rail also carries out its own major overhauls, equipping locomotives to "as-new" standards. By the end of 1981, for example, they anticipate that all of their mainline locomotives will have been retrofitted with "Positive Traction Control". This is a modern wheelslip control system which is further described in section 2.7.

In the United States, extensive remanufacturing of first generation mainline units is carried out by Seaboard Coast Line's Mechanical Department in Tampa, Florida. They turn out one totally rebuilt four-axle locomotive per week at a cost of $300 000 to $400 000 (U.S.) per unit [93]. Although today's market for new locomotives is primarily for six-axle units to service heavier trains or for operations in mountainous territory, these rebuilt four-axle units are still suitable for fast mainline use on flat terrain. They may become increasingly popular in the future. Four-axle units consume approximately 80 000 gallons less fuel per year than six-axle units in applications where they can effectively replace a six-axle unit [32].

In time, as these rebuilt locomotives reach the end of their service life of some 15 years, they will likely be removed from service altogether. At this time the third generation locomotives will be reaching the end of their serviceable life and may provide the next market for remanufactured locomotives.

2.7 Locomotive Adhesion

Another area for improvement is in the ability of the locomotive to "pull hard without slipping". In many cases, the number of cars that can be assigned to a locomotive is determined, not by the power of the engine, but by the ability of the steel wheel to develop enough friction against the steel rail to permit the load to be hauled up grades without slipping.

Any improvements that will allow a locomotive to haul more load up a grade will represent a significant breakthrough. Electronics is the technology which makes this possible. Electronic systems for detecting and controlling wheel slippage are now being implemented in the third generation locomotives. By improving adhesion from a traditional value of 18% to 24% with new slip-control systems, modern locomotives will have more hauling capability up heavy grades [25].

Figure 2.11 illustrates the value of higher adhesion levels to a locomotive. The number of cars assigned to a locomotive consist, is determined by the maximum load it can pull up the steepest or ruling grade of the section over which the train is dispatched. The magnitude of this load is determined by the tractive effort the locomotive can generate at the limit of adhesion (point where the drive wheels start to slip). For a constant locomotive power output, as speed decreases tractive effort increases up to the point where the wheels start to slip. At this point, power output of the locomotive must be reduced to prevent further wheel slippage. Trains are usually loaded to less than their maximum capability. In extreme cases, the combination of adverse rail conditions and an overloaded train may stall it on the ruling grade.

The limit of adhesion usually occurs in the range of 5 to 10 mph depending on the locomotive's power rating and number of axles. In sections of track other than the ruling grade, locomotive speed is governed by available horsepower rather than adhesion.

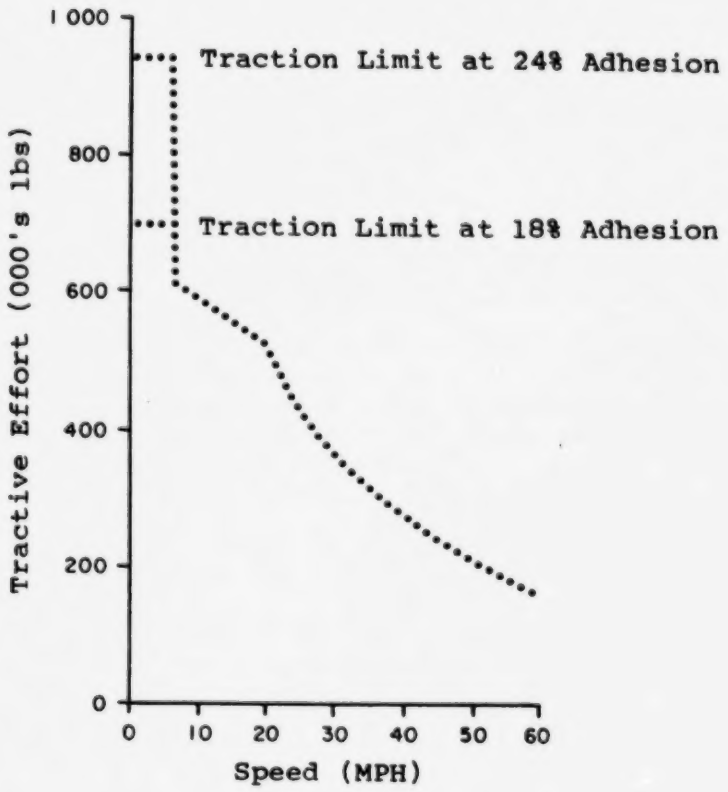
For a 390 000 lb., six-axle locomotive increasing the coefficient of adhesion from 18% to 24% raises the maximum tractive effort from 70 000 lbs. to 94 000 lbs., before the locomotive has to reduce power to prevent wheelslip on the steepest grade of its run.

The latest slip-control devices generate maximum adhesion by allowing drive wheels to slip at a controlled rate of 1 to 2 mph with respect to the rail, rather than preventing virtually any slippage between the wheel and rail.

The Positive Traction Control (PTC) [11,33] system has been developed over a period of several years at Canadian National's Research Centre and is now in use on 400 four-axle

Figure 2.11

TRACTIVE EFFORT VS. SPEED



For a 390 000 lb, 6-axle locomotive increasing the coefficient of adhesion from 18 % to 24 % raises the maximum tractive effort from 70 000 lb to 94 000 lb, before the locomotive has to reduce power to prevent wheelslip on the steepest grade of its run.

locomotives. The PTC system has recently been licensed to Vapor Corp. for worldwide manufacture and marketing.

In the PTC system individual axle-generator measurements of rotational velocity are electronically processed to determine the rotational acceleration of each pair of wheels. When an increase in this value indicates incipient slippage, the system momentarily reduces alternator output enough to reduce the slip, also applying sand as necessary. Differential axle speeds are also monitored and used as a secondary factor in control.

CN has demonstrated usable traction increases of at least 15% to 20% with PTC under its widely varying service conditions. The projected retrofit price is from $10 000 to $20 000 per unit, depending upon the particular model of locomotive to which it is applied. The first 50 units were built by the CN Research Centre and the remainder fabricated commercially by the Vapor Corp. CN is now starting a program of retrofitting another 300 units with a six-axle version of PTC at a rate of 50 to 100 locomotives per year as they become due for major overhauls. They anticipate that all of their mainline locomotives will be PTC equipped by the end of 1981 [32].

General Electric uses the "Sentry Adhesion System" [11] for its new third generation four and six-axle locomotives. In this system the primary detection of incipient slippage is by monitoring differential axle speeds with axle generators. First stage correction is an automatic sand application. Further slippage (also detected by an individual-axle angular-acceleration circuit) results in a second-stage correction adding a small tractive effort reduction to the sanding; a gradual automatic reapplication of full power then occurs. Larger slips or motor overspeed indications result in a larger power reduction and a wheel-slip indication on the control panel, again followed by power restoration as conditions improve.

General Electric has measured adhesion levels around 25% under adverse curvature and track conditions. It believes that such improvements will greatly broaden the application for high-horsepower four-axle units.

The "Micro-Limit Slip Detection System" [11], built by Bombardier Inc., in Montréal, uses General Electric's shaft generator. Both angular acceleration and speed-differential factors are used in its solid-state logic to allow reliable operation in the high-tractive-force creep zone. A summing circuit provides power reduction proportional to slippage severity and automatic sanding, with subsequent power restoration. Bombardier projects a 20% increase in effective adhesion over its previous locomotives.

General Motor's "Super-Series Wheel Creep Control" [11] uses a small Doppler radar unit beneath the locomotive. The

radar scans the roadbed and determines true ground speed. A solid-state electronic unit compares this with traction motor speed to generate commands maintaining creep within the range for optimum tractive force under the prevailing rail conditions. First-stage correction is by power reduction; greater slippage brings sanding into play. To minimize sand consumption, manual sanding is automatically precluded except when starting and under emergency braking conditions. Based on extensive road testing, General Motors claims a 33% increase in adhesion from 18% to 24%.

The Pressductor Adhesion Control system is manufactured by General Motors EMD under license from the Swedish firm ASEA. It is for use in high speed passenger rail service in the Northeast corridor. A similar system is used on EMD's 10 000 h.p. electric freight locomotives used in captive unit train service on the automated Black Mesa and Lake Powell Line in Arizona.

The Swedish ASEA locomotive designs use a slip-control system based on a torsional vibration phenomenon. As the axle reaches its limit of controlled creep, one wheel or the other will start to slip and set up an oscillation at the torsional resonant frequency of the wheel-axle assembly. This vibration is used as the signal of incipient slippage. Power is then momentarily reduced. This system is able to achieve sustained adhesion levels of 25% under poor rail conditions.

To summarize, the improvements in wheel-rail adhesion will have a significant effect on future rail operations, as this directly governs the number of cars a locomotive can pull up the ruling grade. Future adhesion controls for diesel-electric locomotives will use solid state controls capable of reacting more quickly to changes in adhesion conditions at the drive wheels. The current state-of-the-art systems detect wheel slippage by various means and then reduce the power output of the main generator. Solid state circuits can reduce power to the traction motors immediately without waiting for a reduction in the main generator output to prevent slippage before it happens. Power can also be controlled at individual axles rather than by reducing power at all axles or pairs of axles. This is particularly important when a locomotive starts up. At start-up the weight transfer from the leading to the trailing axle, ranges from 15% to 25% of the normal axle load [28]. Future adhesion systems should also aim at reducing the torsional vibration in a drive axle when it reaches its adhesion limit, in order to reduce fatigue and possible breakage.

Future locomotives generating 30% adhesion levels are possible. This would give 25% more pulling effort over present day units equipped with slip-control and 66% more over earlier units not equipped with slip-control.

2.8 AC Traction

Since the introduction of diesel locomotives in the 1940's, traction motors have undergone a steady evolutionary development up to the present day. Today's locomotives are propelled by heavy-duty DC motors mounted on each axle and are powered by the DC generator or alternator and rectifier of the diesel locomotive. The contact brushes used to transmit power to a DC traction motor have the inherent problem of conducting heavy currents at high voltage. This often produces wear and occasionally a major electrical failure within the motors.

With the development of high performance, high voltage solid state devices such as thyristors, the technology is at hand to convert from a DC motor to a more rugged and reliable AC motor. Retarding this development is the fact that thyristors of the required size are very expensive. As a result, the AC motor cannot yet be justified economically. However as with other solid state technology, the state-of-the-art is rapidly advancing and the economics of AC motors for railroad propulsion will make it favourable for use in future locomotives.

Development of the AC traction motor dates back to research first carried out in Germany in 1965. It was based on the idea of developing a universal drive system suitable for both passenger and heavy freight usage. The first prototype was a 2 500 h.p., six-axle diesel-electric locomotive, built in 1971, by Brown, Boveri and Cie AG in Mannheim, West Germany [34]. Currently, operational evaluations of three-phase traction locomotives are being carried out in six countries in Europe. The Transport Canada Development and Research Centre in Montréal has been supporting Canadian studies and research into AC traction since 1975. The purpose of the research is to define a version suitable, for North American Railways [35]. Operational prototype locomotives should appear in North America in 5 to 10 years time.

The reasons for increasing interest in AC traction, stems mainly from the fact that it has no commutator (in an induction motor no current has to be transmitted to a moving rotor) and thus offers the following advantages [36,34]:

a) less maintenance since there are no commutators to inspect, brushes to replace or brush holders to maintain. Their rugged construction makes them particularly approriate to the harsh Canadian environment;

b) lower weight allows the motor to run at higher speeds to develop more power for a given size of motor;

c) no power loss at high speed since no reactance voltage is built up in a commutator;

d) higher capability for regenerative braking since there is no commutator to impose a limit on the power output during braking;

e) lower first cost;

f) changeover from traction to braking is a natural function of the motor. Dynamic braking can be provided right up to zero speed; and

g) flange and rail wear is reduced due to lower unsprung weight (a conventional bogie weighs 22 tonnes while the AC system weighs 15 tonnes).

The disadvantage of the system is the need for sophisticated three-phase variable frequency controls. Solid state electronics must be used to control both the frequency and the voltage of the power supply to the motors. In the case of electrified lines, measures must be taken to reduce inductive interference which can disrupt communications equipment and in some cases build up dangerous induced voltages in other conductors running parallel to the locomotive supply catenary.

2.9 Radio Controlled Locomotives

To furnish additional tractive power for increasing train capacity on steep grades, many railroads have introduced unmanned radio controlled "slave" locomotives which are inserted in the body of the train. On CP Rail's main line between Calgary and the Pacific Coast, four mountain ranges must be crossed with ruling grades of up to 2.2%. On the steepest of these slopes, the maximum tonnage for a conventional train handled by four six-axle units is 4 535 tonnes. By inserting a three-unit consist under separate manual control, a 7 620 tonne train can be taken up the 2.2 grade [37]. Radio controlled slave units have been used in this territory since 1969. With a four-unit slave consist, trains grossing 12 000 tonnes are now being handled through this route.

In a slow sustained movement, as in ascending a long grade, slack action between freight cars is not a problem. It is most pronounced on rolling territory where slack "run-in" and "run-out" between freight cars can generate forces high enough to break the couplers which join the cars together. Removing one or more units from the head end and placing them further back in the train under radio control, reduces the problem of slack action between cars. The Québec North Shore and Labrador Railroad, for example, was able to increase the number of cars from 165 to 280 in its operations. This serves to increase capacity without having to resort to double tracking or other measures.

On CN Rail lines, track profiles do not require the same amount of tractive effort to overcome the grades. Hence,

with their current trains of about 110 cars they do not need remote units. If train size was to grow to 150 cars, then remote units would be required. Train size is often governed by the capacity of the loading and unloading points and the length of sidings and passing tracks.

Compared with conventional head end handling, radio controlled mid-train locomotives offer:

a) increased train tonnage;

b) better control of slack;

c) improved braking response;

d) shorter stopping distance; and

f) faster charging of the brake system.

As the slave locomotive implements a brake application at the same time as the lead locomotive, the overall braking time is reduced by 50%.

The operation of radio controlled locomotives is particularly attractive in cold climates where the lengths of conventional trains are drastically reduced by increased air leakage from the brake pipes. Figure 2.12 indicates the advantages of remote operation in cold weather.

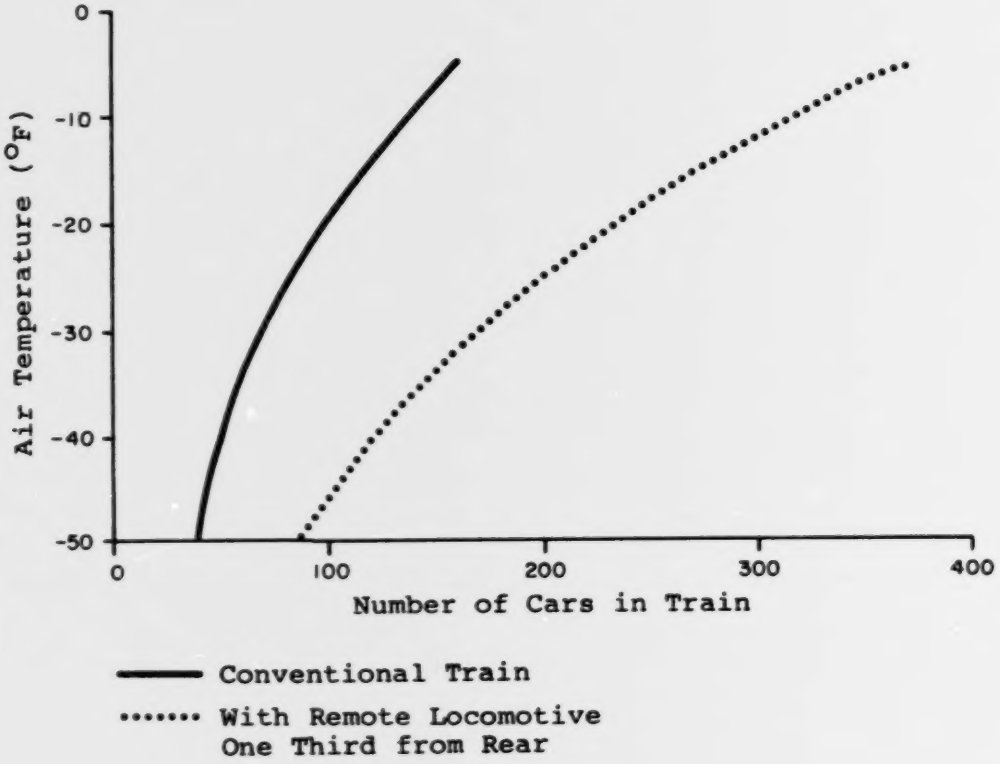
In the actual operation of remote consists, it is not necessary or always desirable to have them operate synchronously with the head end units. This relates to an important concept in remote operation known as the "node" point. This is the point at which freight cars, pulled by one set of locomotives, meets those pushed by the next set. This is illustrated in Figure 2.13.

The location and control of the node point is an important factor in preventing coupler failures due to slack run-in and run-out. These failures which were common in the early stages of remote unit operation have been eliminated through careful independent control of remote units.

One of the disadvantages of this system is the loss in fuel economy since maximum power of all units is only required a small portion of the time. Multiple locomotive consists spend much of their time with all units in intermediate throttle positions. Notch eight, the higher power setting, is the most efficient setting for the turbo-charged units. A multiple unit throttle control device, known as the "fuel saver", is used to keep a subset of locomotives in notch eight (with the others in notch one) whenever the resultant tractive effort would match that of all units in an intermediate notch position.

Figure 2.12

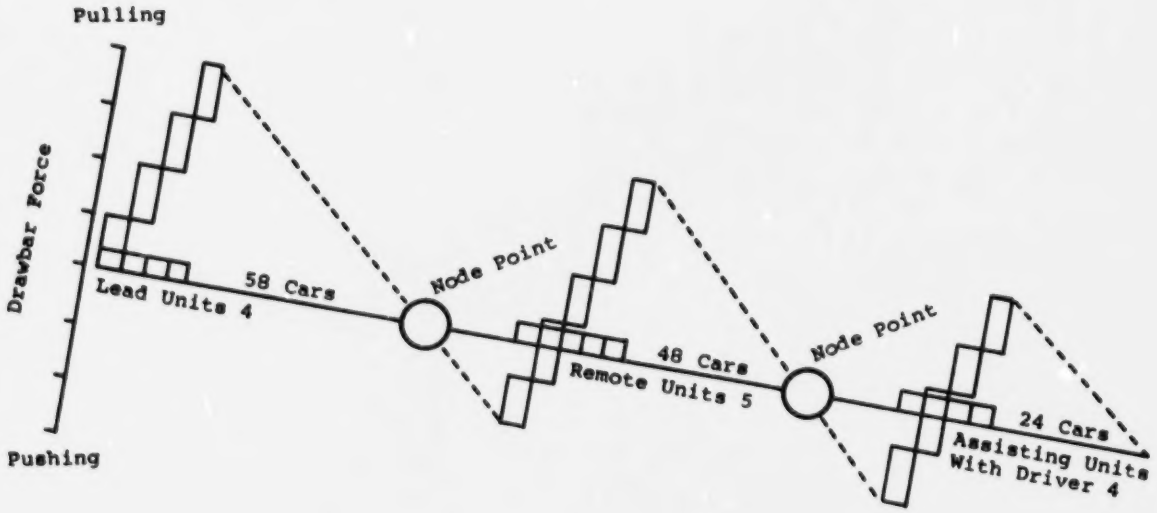
ADVANTAGE OF REMOTE LOCOMOTIVES FOR INCREASING TRAIN LENGTHS IN WINTER



Source: [37]

Figure 2.13

DRAWBAR FORCE DIAGRAM OF A 4-5-4
POWER ARRANGEMENT HANDLING 130 CARS
ON A 2.2% GRADE



In balanced operation (all portions of train moving at same speed) both nodes occur at a safe distance ahead of remote and assisting locomotives.

Source: [37]

The description of this device is found in section 2.4.

The latest development in improving the handling of remote unit consists is the advent of the on-board computer which was introduced in 1980 [38]. The computer is aimed at providing the engineman, located in the head end unit, with information on the unmanned units as to performance, malfunctions and information normally displayed by in-cab instrumentation. Benefits expected to result from the system include: improved fuel economy due to better train control and lower maintenance requirements due to better identification of malfunctions.

2.10 Other Components

The subject of wheel/rail interaction for both locomotives and freight cars has been an area of continuous on-going research.

The objectives are to reduce both wheel and rail wear caused by today's heavy axle loadings and to improve safety by reducing fatigue failures in both track and vehicle components.

Future developments will include the type II steerable axle truck (described further in section 5.4) which reduces stress on curved portions of the track.

Locomotives with larger 52" diameter wheels, compared to current 40" wheels, will reduce rail wear, improve traction, and increase wheel life. Locomotive wheels generally last from 12 to 42 months or 200 000 to 400 000 miles depending on the service. They may be remachined twice during this interval before being scrapped [30].

Locomotive axle loadings will remain fixed in the range of 62 000 lbs. per axle. If future axle loads are increased to improve tractive effort capability, then track and roadbed must be upgraded to prevent damage. Typical four-axle locomotives now weigh 250 000 lbs. and six-axle locomotives weigh 368 000 lbs.

Chemical companies are reportedly developing antifreeze solutions suitable as a locomotive coolant. This, together with modern engine purge controls, (see section 2.3) will allow locomotives to be shut down when not in use during freezing temperatures. At present the current cost of providing some 300 gallons of coolant per engine is high. However, the main reason for not using antifreeze is the possibility of ethylene-glycol leaking into the crankcase oil. This would cause rapid deterioration of the oil and consequent engine damage [13].

The braking system for freight trains includes the service air brakes and the engine dynamic brakes. The service brakes use a compressor on board the locomotive, supplying air

to operate friction brakes on the locomotive and on each of the freight cars. The latest innovation in this area involves using micro-processors to adjust braking effort in individual cars according to the weight being carried.

Dynamic braking initially was a feature used solely in hilly or mountainous regions. Now with advances in technology, roads with undulating profiles can use it effectively. In this mode of operation, the locomotive traction motors are made to operate as generators (which offer resistance to rotation). The electric energy produced is dissipated as heat by dynamic brake grid elements on the side of the locomotive. If AC traction motors are adopted in the future, this will offer two advantages. First, dynamic braking is a natural function of the AC motor compared to the DC motor which must be switched over. Secondly, dynamic braking continues right down to zero speed, whereas the DC motors are most effective between 18 and 25 mph [39]. Future dynamic brake developments will be aimed at increasing their range of speed effectiveness and possibly in the long term finding a method of storing dynamic brake energy from either AC or DC motors.

The major problem in train braking is the reaction time required for air-operated systems in long trains. Future systems may use inductive couplings between cars which use an electric signal to activate the air brakes on each car without the delay of an all-air system. This may present a problem of comparibility between these and conventionally operated brakes. Establishing an electrical connection over the length of a train will be a probable major advance, since it provides the opportunity for many other control and monitoring functions to take place. One prime example of this is on-board "hot-box" detectors for the detection in the locomotive cab of overheated bearing journals. Overheating of axle bearings is a major cause of axle failure and subsequent train derailments. Older freight cars which have solid bearings are more likely to fail than are the newer roller bearing types. Retrofitting all freight cars with roller bearings is not practical and therefore hot-box detection is considered as the viable alternative.

2.11 Summary

Beginning with the introduction of the first diesel-electric locomotives in road service in 1948 some 3 100 diesel units rapidly replaced 5 000 steam engines as a source of motive power. With the introduction of the exhaust gas driven turbo-charger in 1959, the second generation diesels took a quantum leap in power. The trend towards ever increasing power outputs continued until fuel prices started to rise rapidly in 1973. More recent developments have been aimed at improving fuel economy, reliability, and maintenance rather than increasing power. The third generation of diesel-electric locomotives now being introduced by the three major North American manufacturers feature:

a) a 7% increase in fuel economy;

b) on-board diagnostics for identifying faults, or malfunctions and more extensive use of micro-processors for the control and monitoring of train performance; and

c) advanced wheel slip control systems which permit locomotives to haul up to 33% more load-up ruling grades.

Further fuel savings are being realized through more careful control of train operation, maintenance, and education of operators on train simulators.

The average mainline locomotive now costs about $950 000 and has a life expectancy of 15 to 20 years. Rebuilding locomotives at a cost of about $200 000 each is an increasingly popular alternative to the high cost of new units.

Near future developments are not expected to include any radically new technologies before 1985. Developments now in the research stage may be implemented in the medium to long term future. Alternative fuels are being tested in full scale locomotive engines. Dual-mode locomotives capable of operating on both diesel and electric power are on the drawing board. These may be used for electrification of heavy grades as an alternative to complete main line electrification. Wayside energy storage systems are a long term technology compatible with electrification on steep grades. The energy of a train on a downgrade is recovered through regenerative braking and stored in a wayside flywheel unit for use by the next train ascending the grade.

A 20% increase in peak power output of current engines without increasing fuel consumption may be possible by recapturing waste exhaust heat energy and using it to drive a Rankine Cycle Turbine. This would be a significant step to improve the efficiency of the diesel engine.

In summary, the most important locomotive developments in the short term are those which relate to fuel efficiency and in the longer term to alternate fuels and locomotives. With high capital and labour costs, developments which improve productivity and locomotive availability and maintenance are a close second. Finally, those technological advances which increase locomotive power without improving fuel economy or increasing reliability have generally low favour with the operators.

Chapter 3

ALTERNATE FUELS

3.1 Introduction

Alternate fuels for railroad motive power have existed for many years. Interest in them has only now been sparked by increasing concern over energy suppliers. Alternate fuels may be broadly categorized as substitute, hybrid, broadcut or synthetic fuels.

Substitute fuels entirely replace the number two diesel fuel now used by railroads with some other form of energy, (e.g. hydrogen). These fuels would require major modifications to power plants.

Hybrid fuels combine diesel fuel with other liquid fuels (e.g. alcohol) in order to "extend" the diesel fuel. The hybrids normally require minor modifications to engines.

Broadcut fuels are simply a diesel fuel for which the range of acceptable characteristics have been widened in order to increase the amount of fuel available from the refining process. Few engine modifications are required for this type of fuel.

Synthetic fuels are identical to conventional number two diesel fuel, but are derived from non-conventional sources such as tar sands, shale oil and coal. Tar sands derived diesel fuel is already supplying 6% of Canada's railroad needs [2] and is used without engine modification.

3.2 History of Development

In the 1940's, the conversion from coal-fired steam engines to diesel locomotives brought with it a six-fold increase in the energy efficiency of locomotives. Coal and propane burning turbine locomotives have been used in the past, but were eventually withdrawn from service due to operational difficulties. Rail electrification is now favoured by energy conservationists, but railroads lack the capital needed for the large initial investment required. (Electrification is further discussed in Chapter 4.)

Current research is aimed at developing alternate fuels which can be burned in existing diesel engines without any loss of performance and with minimal engine modifications. The long

term effects on the engines and suitable hardware modifications are also being researched. CN Rail has been co-operating with the South West Research Institute in San Antonio, Texas, to investigate the problems associated with operating medium speed (locomotive type) diesels on a variety of fuels. The direction which alternate fuel development should take is difficult to ascertain as it is governed by the relative prices and availability of the potential fuels. Implementation of alternate fuels is still in the mid-term future from five to ten years away.

The current choices of alternate fuels include: diesel fuel hybrids which mix diesel with other fuels, substitute fuels which completely replace diesel fuel, and broadcut or "off-spec" diesel fuels which are diesel fuels with a wider specification range.

3.3 Hybrid Fuels

Hybrid fuels are a mixture of diesel fuel with another combustible material creating a blend suitable for use in conventional diesel engines. Examples of such hybrids include alcohol or carbon-in-oil solutions used to extend the diesel fuel. Alcohol for example is mixed with diesel fuel in the fuel lines and injected into the engine through a single injection system. The amount of alcohol substitution without power loss ranges from 12% to 32% of energy requirements depending on power output and whether ethanol or methanol is used [40]. The limiting factor is engine knock which reduces engine performance and reliability at higher mixtures.

Higher mixtures of up to 90% alcohol are possible but require major engine modifications (see section 3.4). At this rate of substitution, alcohol becomes a substitute fuel.

Alcohols have a lower heat of combustion and as a result will have a higher specific fuel consumption for the same power output when compared with pure diesel fuel. The typical heat contents are:

Diesel	20 000 Btu/lb.
Ethyl Alcohol	13 000 Btu/lb.
Methyl Alcohol	9 600 Btu/lb.

The long term engine effects and hardware modifications required for hybrid fuels are not yet known, but are now the subject of intensive research at the South Western Research Institute [40].

3.4 Substitute Fuels

Unconventional fuels such as straight alcohol and gaseous fuels are unsuitable for use in conventional diesel

engines without extensive modifications. The modifications would require either adding an ignition system or adding a second injection system for introducing small amounts of diesel to initiate combustion.

Some of the alternative fuels in diesel engines include: hydrogen, propane, alcohol, liquid natural gas, coal-in-oil suspensions and synthetic diesel fuel (see section 3.5). Still other forms of energy such as coal, electricity, (Chapter 4) and petroleum products other than diesel fuel may be used in non-diesel type machines.

Hydrogen offers promise for the future as a substitute fuel. It has a heat content of 31 000 Btu/lb. compared to diesel fuel with about 20 000 Btu/lb. Hydrogen is more difficult to produce, handle and distribute due to its low density (it is more prone to leakage than are other gases). It has a high energy content, is clean burning, and is not petroleum based. Hydrogen can be used to power locomotive diesels but will require more extensive modifications to the engines than do diesel/alcohol fuel mixes [41]. The cost per unit of energy for hydrogen is also about three times higher than that of diesel fuel according to a 1977 estimate. This difference will be reduced in the future as the technology to produce hydrogen becomes more advanced.

Hydrogen as a railroad motive power fuel presents some problems since it must be carried in a cryogenic liquid state in a separate "hydrogen tender". This is usually a low pressure, double walled, vacuum insulated tank. A 3 200 gallon diesel fuel equivalent tender is estimated to weigh 79 000 lbs. (gross) and cost $120 000.

The fuel tenders will add dead weight, not usable for traction, and added length to locomotive consists. In addition they may pose a safety hazard in the event of a collision. An alternative to gaseous/liquid storage is in the form of hydrogen hybrids. This process is still not fully explored.

A 1976 report predicted that hydrogen will supply 11.8% of the energy requirements in the transportation sector by the year 2000 [43]. The future use of hydrogen however, will depend primarily on the cost of producing it. The high cost is now its major detractor.

Alcohol fuels have been tested in the laboratory substituting up to 90% of the fuel energy requirement of the diesel engine with methanol [40]. Ten percent of the energy requirement is supplied by diesel fuel in order to initiate combustion in the diesel engine. This is necessary because current engine design does not provide a separate ignition system. As indicated in section 3.3, methanol has only 50% of the heat content per pound of diesel fuel. At a 90% substitution rate this will increase fuel consumption by 45% for the same power output.

Alternate engines also provide an opportunity for the application of substitute fuels. One proposal for a modern coal burning steam engine was discussed in section 2.2. The locomotive achieves a 15% thermal efficiency compared to a diesel's 30% efficiency. Fuel costs are estimated to be 33% less than for a comparable diesel unit at 1980 prices.

The General Electric/ALCO turbine locomotives in service with Union Pacific from 1951 to 1968 were fuelled by a lower grade bunker "C" oil (see section 2.2). The gas turbine has the ability to burn a variety of fuels including propane, natural gas, residual fuel, crude oil, etc. The best prospect is liquified natural gas which avoids the past problems of ash build-up in the turbines. Turbine efficiency drops off rapidly below peak output and over a typical duty cycle and would be only about 50% as efficient as the diesel. The use of turbine power and fuels will depend primarily on the availability of fuels for conventional diesels. The turbine cannot be considered as an engine which will save energy unless its efficiency can be improved relative to diesel power.

3.5 Broadcut Fuels

The "off-specification" or "broadcut" diesel fuels have been defined as fuels with one or more properties which do not lie within the currently accepted range of specifications [28].

If fuel specifications for content and quality of number two diesel can be relaxed or broadened, then the refining requirements can be reduced. This would increase the efficiency of the refining process achieving an estimated 5% higher yield in refining crude oil into a so-called "broadcut" fuel with a wider range of characteristics [40,44].

This would involve using a wider range of specifications for cetane number, viscosity, boiling range and sulphur content to reduce the number of steps required in the refining process.

3.6 Synthetic Fuels

The synthetic fuels are refined from crude oils derived from non-conventional petroleum sources, such as shale oil, tar sands and coal. The diesel fuel refined from these synthetic crudes is similar to conventional diesel fuel and can be used with little or no engine modification. Shale and tar sands oils are extracted by heating the mixtures to release the oil. Oil can also be produced from coal through hydrogenation. This process involves combining coal with hydrogen to produce a synthetic crude oil.

Synthetic coal-derived fuel has been used in the laboratory to substitute 90% of the diesel fuel energy without major engine modifications or significant loss of power.

In Canada synthetic crude derived from tar sands oil is already used to supply 6% of the fuel consumed by railroad motive power equipment according to 1978 statistics [2]. In 1978 the price of this fuel was 43.6¢ per gallon, and was less than that of diesel fuel at 50.4¢ per gallon. The synthetic crude used as a feedstock for refineries has a lower price since it is classified for tax purposes as a crude oil. The characteristics of fuels produced from the lighter crude of the tar sands oil are such that they may be burned in diesel locomotives with little or no modification.

In the United States, diesel fuel produced from shale oil by the PARAHO process is essentially identical to conventional Number two diesel fuel [40]. It has been tested in marine diesel engines but as far as it is known, it has not been used extensively in locomotives.

3.7 Summary

The alternate fuels for railroad motive power may be broadly categorized as hybrid, substitute, broadcut or synthetic fuels.

Hybrid fuels containing alcohol with diesel fuel can replace from 12% to 32% of an engine's energy requirement with methyl or ethyl alcohol without power loss. Higher mixtures will require major engine modifications. The heat content of alcohol is roughly 50% of that of diesel fuel. This will increase fuel consumption accordingly in order to maintain power output. Hybrid fuels will likely appear in locomotive prototypes within the next five years.

Substitute fuels which replace diesel fuel altogether require major engine modifications or the introduction of new engine types. The best substitute fuel appears to be hydrogen. It has a heat content of 50% higher than diesel fuel and is very clean burning. Its present drawbacks include the high cost of production and difficulties in handling the gaseous fuel. At this stage the use of hydrogen fuel for motive power is still a laboratory study.

Other substitute fuels such as coal, alcohol, and various petroleum products are also being investigated. The use of alcohol, substituting up to 90% of the diesel fuel energy, is possible with major engine modifications and no significant power loss.

Broadcut fuels for locomotive use are diesel fuels for which the specifications are relaxed, in order to broaden the range of fuels which may fall within the category. This will permit an estimated 5% higher yield from the refining process for diesel fuels by reducing the number of refining steps

required. This fuel will require very little modification to existing diesels. Prototype locomotives using these fuels should appear within the next five years.

Synthetic fuels are fuels which meet the current diesel standards, but are derived from non-conventional sources such as tar sands, shale oil or coal. Tar sands oil now supplies 6% of Canada's locomotive consumption. These fuels require virtually no engine modification.

Laboratory tests of various alternative fuels are being carried out to determine what modifications are needed and what long term effects these fuels will have on current engines. Future fuel supplies for transportation in general will likely include a wide variety of fuel types rather than any one dominant form. The railroad industry will favour a limited number of alternate fuels in order to standardize equipment and facilities as much as possible.

Chapter 4

ELECTRIFICATION

4.1 Background

One of the most far reaching developments in the foreseeable future is that of electrifying the main lines of both major Canadian railway companies. This would permit substituting in great part the present diesel-electric locomotives with full electric locomotives. Electrification is not technology dependent as the technology is already in operation on 13% of the world's railroads. Although the operating costs of an electrified system are lower, the high initial cost of the motive power, catenary and other fixed plant components are a barrier to its implementation. It appears inevitable that the first stages of electrification will be realized in North America by the turn of the century. There is no evidence to suggest that petroleum fuels will not continue to increase in price relative to electricity. In the future, alternate fuels may be reserved for other modes of transport. In addition, conversion to electric power is consistent with long term national goals to achieve energy security and to reduce dependence on foreign oil. Electrifying high density main lines has the potential to reduce diesel fuel consumption by 50%. However initial costs are in the range from $600 000 to $1 000 000 per mile. Electrification now appears to be a matter of "when" and not "if".

The world's electrified railroads carry 35% of the total ton-mile of cargo [45]. In Western European countries about 90% of their ton-miles are produced on electrified rail lines. Other countries such as the Soviet Union, South Africa, China, Japan and India (which is converting directly from steam to electricity) are in various stages of electrification. Taiwan and South Korea are electrifying their main lines from the outset.

In North America, electric lines have been operating in the northeast United States corridor since 1907. In Canada electrified lines include a CN line operating in the tunnel through Mount Royal in Montréal, the British Columbia Electric Railway (essentially an intra-urban passenger railway) and seven miles of automated ore-haul operation near Sept-Iles, Québec [1].

There are plans to electrify an ore-haul branch line of the Cartierville Railroad in Northern Québec. The Transportation Development Centre of Transport Canada will be

involved in monitoring this project as a pilot electrification demonstration.

The most modern electric freight operation in North America is the Black Mesa and Lake Powell Railroad in Arizona. It uses 10 000 h.p. General Motors electric locomotives, operating in a private unit ore train operation in Arizona.

4.2 Factors Favouring Electrification

The advantages of electrification stem mainly from the operation of the system once it is in place. The United States Federal Railroad Administration has estimated annual savings in operating and maintenance of $1.5 billion (U.S.) for a 26 000 mile network [46].

These benefits include:

a) lower energy costs which would account for 26% of the annual savings;

b) lower maintenance costs. Electric locomotives have an availability of about 92.5% compared to 90% for diesel-electrics and a maintenance cost roughly 33% that of the diesels. Also a 5 100 h.p. electric locomotive, costing $1.2 to $1.5 million has a life expectancy of 30 years compared to a 3 000 h.p. diesel costing $1 million with expectancy of about 18 years;

c) currently available technology which does not require any major advances to be implemented;

d) a 50% reduction in diesel fuel consumption; and

e) high adhesion, and short-time overload capabilities of electric locomotives which may reduce the number of units required to operate a train over ruling grades in mountainous territory.

When considering the total cost of electrification including stationary equipment and motive power purchases, electrification may still be economically competitive with synthetic fuels. It is also possible that the full synthetic fuel production capacity for several years to come would be used primarily by the highway mode. Electrification will provide the option of selecting the most abundant energy source to provide electric power; be it hydro, nuclear, coal or petroleum.

From a national standpoint, the Canadian Railway Electrification Study in 1976 [47] made the observation that:

"The essence of the case for a serious consideration of electrification at this time is the probability that the supplies of oil are going to decline and oil prices are going to rise progressively as the years go on. This is a basic fact arising out of a steadily rising demand and an ultimately limited supply. In the long run, industrial civilization relies on applied energy. Therefore, safeguarding of the energy supply is of the highest priority in the Canadian national policy" [47].

4.3 Arguments Against Electrification

In the past, resistance to electrification has come from within the railroads primarily because of the high capital investments required which they feel would be better utilized in other areas of the railroad system. Some of the problems and arguments associated with electrification are as follows:

a) While the conversion from steam to diesel completely eliminated the facilities required for steam locomotive servicing, the same will not take place for the conversion of diesel to electric. There will continue to be diesel units for servicing industry, branch lines, etc. Duplicate facilities will have to be maintained;

b) The signal and communication systems used for electrified lines must be buried or otherwise protected to prevent inductive interference or noise in the signal;

c) Civil reconstruction will be necessary to provide adequate clearance for catenaries, in tunnels, or under bridges, where adequate clearance does not already exist. Over at least the last decade, this has been provided for in civil construction;

d) The first generation of electric locomotives may not have the high reliability and standardization of existing diesel units. There will likely be a period of adjustment before the maintenance advantages are realized;

e) From the railroads' standpoint, capital will be a limited resource over the next seven years. The large amount and high cost of capital required to electrify the lines, modify signalling and communication systems, and to purchase electric locomotives would be more effectively spent in upgrading other components of the existing system. Railroads are not limited by availability of motive power but rather by inadequate rights-of-way,

outdated signalling and control systems and the need to improve classification yards [11]. Therefore very little of the capital needed for electrification will come from within the railroads;

f) In Europe where electrification is prevalent, railways use fast, lightweight trains with fewer cars. In North American operations long, heavy, slow trains are used. For electrified lines it is much more expensive to supply a small number of very high point loads (large trains) within the system than to keep the same tonnage moving in the form of a large number of smaller trains [46]. The subsequent argument against using more trains, is the higher labour cost for additional crews;

g) Utilities will have to be upgraded to meet the additional demand;

h) Catenary maintenance will become an additional cost item to the railroad;

i) Each diesel-electric locomotive produces the electricity which it requires. When derailments occur, the trains are passed through the wreck area in what is called "fleeting" of trains. With electric locomotives their large power demands would upset the basic power supply to the surrounding region. The cost of power could also vary with the time of day so the dispatcher would order the trains during periods of low power rates;

j) The purchase of power would likely be from provincial power grids. No railway wants to be governed by a party in power whose policies towards the railway may change; and

k) While an electric locomotive at about 90% efficiency is a more economical user of energy than is the diesel locomotive at about 30% efficiency, the source of electric energy has a strong affect on overall energy efficiency. Thermal generating stations are about 32% efficient while hydro-electric generating stations are about 85% efficient. If all electrical power consumed by locomotives was thermally generated, overall energy efficiency of all electric traction would actually be less than that of diesel [48].

The ultimate decision as to whether or not electrification of railways will take place lies with the railways themselves. Their participation will be necessary to make the conversion viable. As the price gap between oil and

electricity widens, railroads will become more favourably inclined towards electrification [7], but the problem of initial funding must be overcome.

4.4 Cost of Electrification

In 1976, the Canadian Institute of Guided Ground Transport [47] estimated a cost of $1.0 to $1.8 billion to electrify 9 500 miles of track. The electrification was to include 501 miles of CNR track from Edmonton to Kamloops and 419 miles of CP track from Thunder Bay to Winnipeg. The program would extend over 30 years with an annual investment of $60 million.

A recent electrification study in 1980 by the United States Federal Railway Administration [46] estimates a total capital cost of $14.9 billion or $570 000 per mile to electrify 26 000 miles of track (see Table 4.1). The lines proposed for electrification in the United States carry over 30 million (gross) ton-miles per year each.

With the cost of capital exceeding 18%, the 14% return on the investment from electrification would not be sufficient to encourage conversion on an economic basis. At present, Canada's railways reportedly require a 20% internal return on investment.

Another study for Burlington Northern estimates the cost of electrifying 740 miles of track for moving coal traffic at $780 million or approximately $1 million per mile [11].

4.5 Summary

The major obstacle in the road to electrification is the high capital investment required. Current estimates for fixed plant and motive power run about $1 million per mile and are rising steadily. Most railroads favour electrification if the problem of initial financing can be overcome, although some feel that the money would be better spent elsewhere in the system. The scarcity of capital may well be the factor which ultimately inhibits electrification.

The technology for electrification is already available, and in general it now appears to be a matter of time before it is implemented in North America. Mainline electrification will reduce railroad fuel consumption an estimated 50%, offer lower maintenance and energy costs and allow flexibility in the choice of energy sources used to provide electrical power. High power/high adhesion electric-locomotives may also reduce the number of units required for operations in mountainous territory.

Table 4.1

FRA ESTIMATES OF INVESTMENTS AND SAVINGS DUE TO ELECTRIFICATION

	$
Route Miles	26 000
Traffic (MGTM/Y)	945 800
Investments (Million $)	
Catenary	6 040
Substations	2 620
Signal and Communications	4 400
Civil Reconstruction	1 660
Electric Locomotives	5 240
Total Investments	19 960
Credit (diesel locomotives)	-5 060
Total Capital Requirement	14 900
Annual Costs and Credits (Million $)	
Diesel Locomotive Replacement	-281
Diesel Energy	-1 500
Electric Energy	1 110
Diesel Locomotive Maintenance	-1 360
Electric Locomotive Maintenance	409
Catenary Maintenance	114
Net Annual Savings	1 510
Economics	43 790
Cumulative Savings (29 years)	14 %
ROI	

Source: [46]

Some of the disadvantages of electrification include: the requirement for dual servicing facilities for diesel and electric engines, modifications to signalling systems, some civil reconstruction to provide adequate overhead clearance, reduced reliability of first generation electric locomotives, and a change to the operation of shorter trains with correspondingly higher labour costs.

Chapter 5

FREIGHT CARS

5.1 Introduction

Chapter 5 presents a brief history of the development of freight cars since 1945, describes the state-of-the-art and near future car developments.

Each of the five generic types of freight cars including: box cars, gondola, hopper, tank and flatcars are examined. Also included in the discussion is a review of the evolution of the car types, statistical trends, European developments, aerodynamics, running gear, intermodal equipment and future trends.

5.2 General History of Freight Car Development

5.2.1 Box Cars

Box cars of 40 and 50 ft. lengths in either 40 or 50 ton capacities constituted practically all the models built in the 40 years ending about 1960. The AAR Mechanical Division in co-operation with the American Railway Car Institute, prepared highly standardized designs which were the basis for hundreds of thousands of single and double sheathed cars built over the four decades.

In the 1920's, a 50 ft. wooden box car equipped with steel underframe weighed 65 000 lbs. and had a carrying capacity of 80 000 lbs. In the 1960's, demands for increased length, cubic capacity and weight carrying ability resulted in the 60 and 86½ ft. cars in 70 and 100 ton designs. These were developed initially for automobile parts service. Other high cube designs have also been developed for household appliances [49]. The box car illustrated in Figure 5.1 is a modern 50 ft. general purpose design with a 76 ton capacity.

5.2.2 Gondola Cars

The gondola car is used primarily for hauling ore, coal, forest products, steel products and machinery. It is of heavier construction than a box car and is designed for top loading/unloading of bulk type or primary manufactured commodities which require less protection than that offered by the box car. In 1955, easily removable top covers were added to offer protection to the contents from the weather. Today, these

covered gondolas are widely used to carry steel sheets in coils or bundles. A typical 100 ton capacity gondola car is illustrated in Figure 5.2.

5.2.3 Hopper Cars

The hopper car is similar to a gondola car except for the addition of doors in the floor designed for hauling bulk commodities. It has long constituted one of the largest classifications of freight cars. With growing resource traffic, the hopper car is second only to the box car in numbers in service.

Built first in large numbers during the 1920's for cement service, the past 25 years have seen the covered hopper utilized for a steadily growing number of bulk products requiring protection in transit. The car makes possible bulk movements of materials formerly shipped in bags and barrels or handled in bulk in box cars fitted with grain doors. Some cars have been fitted with humidity control equipment for handling chemicals and food products. A recent development is the use of insulated covered hoppers fitted with mechanical refrigeration equipment for bulk movements of perishables [49].

A typical covered hopper car with manually operated hatches in the bottom of the car is illustrated in Figure 5.3.

5.2.4 Tank Cars

The tank car was developed over a century ago to transport crude oil and petroleum products. Today it is used mainly to serve the chemical and agricultural industries.

Maximum tank car size has increased from the 43.7 ton capacity cars used in 1945 to the current 100 ton designs similar to the illustration in Figure 5.4. Further increases will be minimal as axle loadings are near the 65 000 lbs. per axle maximum. Greater loads would cause excessive rail damage with present freight car wheel size.

The length of tank cars does not vary significantly, since their length is governed by the location of loading standards at refineries and destination points.

Figure 5.5 illustrates the number of tank cars in use by Canadian Railways from 1945 to 1978. The drop in tank car numbers in 1952 is attributable to the introduction of pipelines which took over some of the movement of bulk liquids.

The Railway Educational Bureau, 1809 Capital Avenue, Omaha, Nebraska 68102

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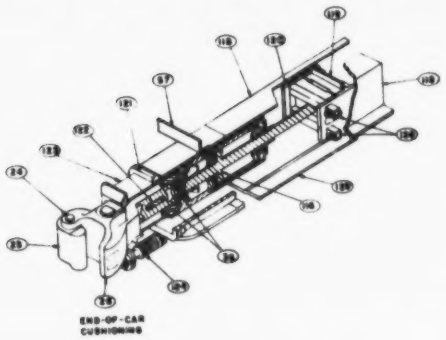

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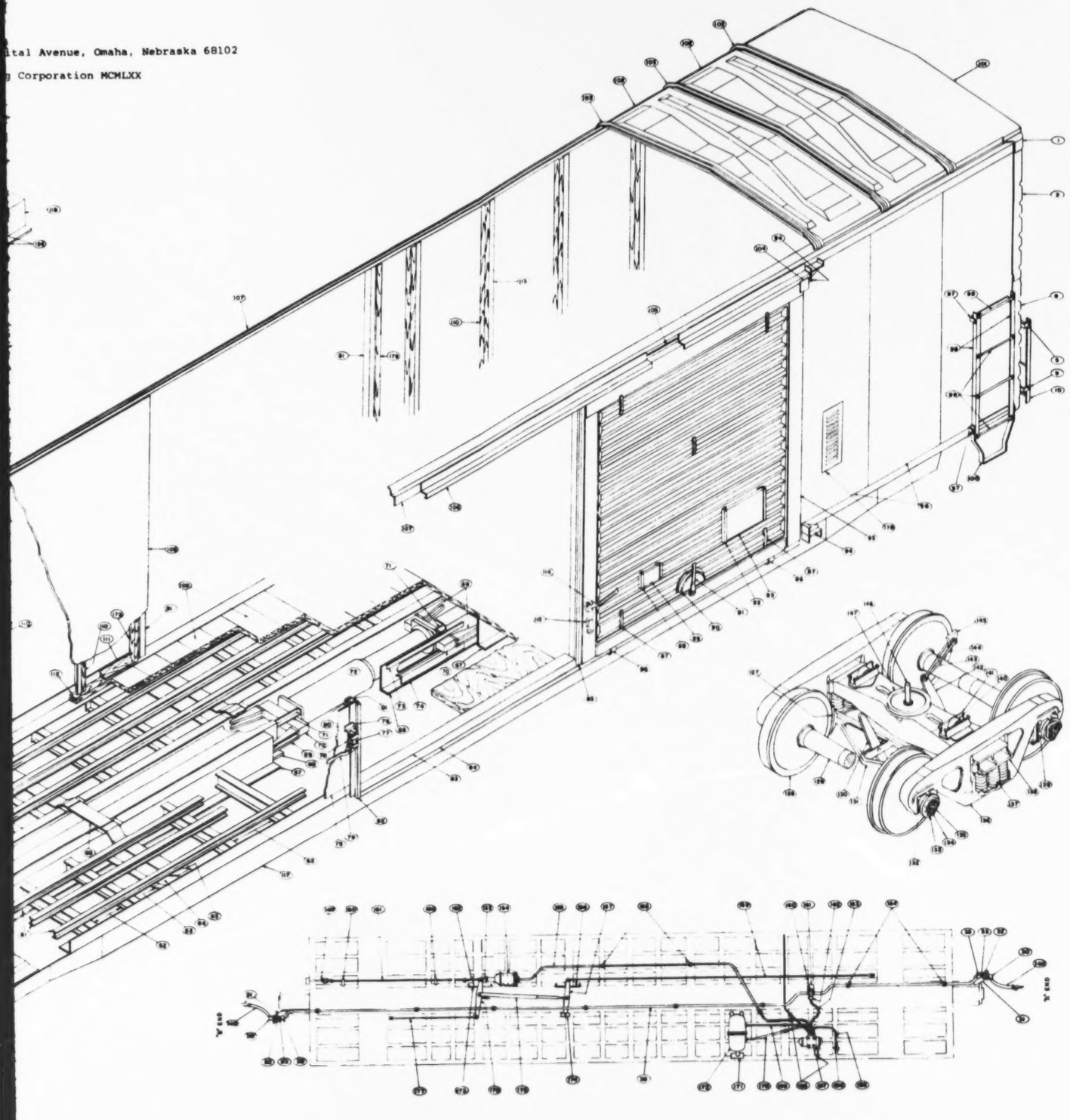
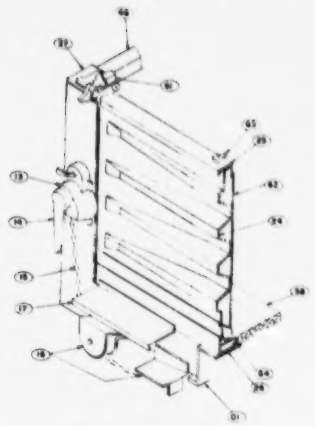
Figure 5.1



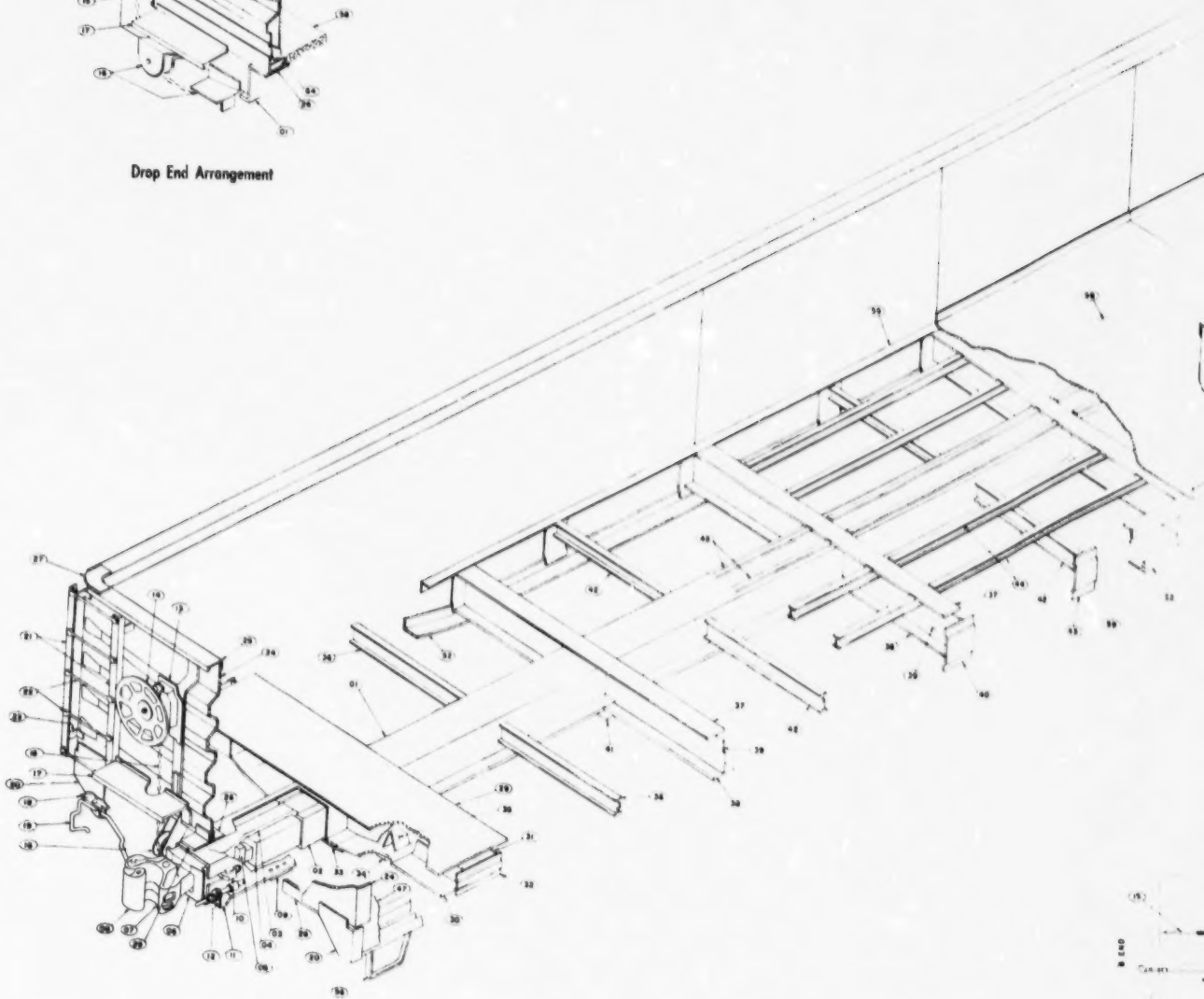
BOX CAR CHART

Steel Sheathed--Cushion Underframe
Length 50' 6" Capacity 154 000 Pounds

1. Corner cap
2. Steel end--top
3. Horizontal end handhold
4. Hand brake housing
5. End ladder support--top
6. End ladder tread
7. Hand brake wheel
8. Steel end--bottom
9. End ladder support--bottom
10. End ladder stile
11. Uncoupling lever bracket
12. Uncoupling lever bracket suppo
13. Uncoupling lever support
14. Telescoping uncoupling rod
15. Uncoupling lever guide
16. Hand brake chain
17. End platform
    (combined crossover and brake s p)
18. End platform support
19. Bell crank
20. Vertical hand brake rod
21. Front draft gear stop
22. Striker
23. Hand brake housing support
24. Coupler knuckle pin
25. Coupler knuckle
26. Type E coupler head
27. Coupler carrier
28. Coupler wear plate
29. Striker flange
30. Angle cock
31. Angle cock support
32. Angle cock "U" bolt
33. Nipple
34. Drafe key washer
35. 45° elbow
36. Draft key
37. Draft key retainer
38. Brake pipe, 1 1/4" (Train line
39. Follower block
40. Coupler yoke
41. Draft gear
42. Rear draft gear stop
43. Rear draft gear stop reinforce nt
44. Sliding sill guide at end
45. Sliding sill guide at bolster
46. Body center plate
47. Body side bearing
48. Body side bearing shim
49. Body side bearing stiffener
50. Bolster bottom cover plate
51. Bolster top cover plate
52. Bolster web
53. End lining retainer
54. End lining
55. End lining nailer
56. End lining nailer filler
57. End sill
58. Corner post
59. End side sheet
60. Side sill
61. Floor stringer
62. Crosstie
63. Crossbearer bottom cover plat
64. Crossbearer web
65. Crossbearer top cover plate
66. Crossbearer top tie plate
67. Center sill--fixed
68. Center sill--sliding
69. Sliding sill cushions top lug
70. Cushion key
71. Fixed sill cushion stop lug
72. Cushioning device
73. Upper reinforcement
    --sliding sill slot
74. Lower reinforcement
    --sliding sill slot
75. Side sheet at door
76. Door lock support
77. Wedge sealing pin
78. Sealing cam
79. Operating lever
80. Door post reinforcement
81. Door post
82. Door stop--front
83. Threshold plate
84. Door track
85. Front edge--door
86. Bottom retainer
87. Door handle
88. Routing cardboard bracket
89. Routing cardboard
90. Lifting lever retainer
91. Lifting lever
92. Placard board bracket
93. Placard board
94. Door stop--rear
95. Rear edge--door
96. Side sheet--intermediate
97. Side ladder support
98. Side ladder stile
99. Side ladder tread
100. Sill step
101. End roof sheet
102. Intermediate roof sheet
103. Roof seam cap
104. Door retainer
105. Door top edge
106. Door top retainer
107. Side plate
108. Side lining
109. Deck board
110. Side post nailer
111. Grain strip
112. Floor side filler
113. Side post
114. Door hasp fastener
115. Door hasp
116. Hydraulic piston
117. Side sill reinforcement
118. Center sill
119. Back stop plate
120. Rear lug casting
121. Striker casting
122. Coupler key
123. Cushioning unit
124. Restoring mechanism
125. Inspection plate
126. Rear cross key
127. Brake shoe
128. Wheel
129. Axle
130. Truck live lever
131. Brake beam
132. Roller bearing adapter
133. Roller bearing end cap
134. End cap retaining bold
135. End cap locking plate
136. Truck side frame
137. Truck spring
138. Truck bolster
139. Roller bearing assembly
140. Truck side bearing roller
141. Truck side bearing housing
142. Truck dead lever
143. Clevis at dead lever
144. Clevis at dead lever fulcrum
145. Dead lever anchor
    --underframe mounted
146. Center pin
147. Truck center plate cast
    integral with truck bolster
148. Air hose
149. Hand brake chain at bell crank
150. Tand brake rod guide
151. Hand brake rod
152. Hand brake chain at cylinder
153. Cylinder push rod
154. Air brake cylinder
155. Cylinder pipe, 3/4"
156. Floating lever guide
157. Floating lever
158. Pipe clamp, 3/4"
159. Top rod, "A" end
160. Branch pipe tee
161. Branch pipe tee support
162. Combined dirt collector
    and cut-out cock
163. Connection hose
164. Pipe clamp, 1 1/2"
165. Retainer pipe
166. Retainer valve
167. ABD control valve
168. Release rod
169. Auxiliary reservoir pipe, 3/4"
170. Emergency reservoir pipe, 3/4"
171. Reservoir support
172. Combined auxiliary and
    emergency reservoir
173. Cylinder lever guide
174. Brake lever fulcrum
175. Brake slack adjuster
176. Cylinder lever
177. Top rod, "B" end
178. ACI label
179. Door post nailer



Drop End Arrangement



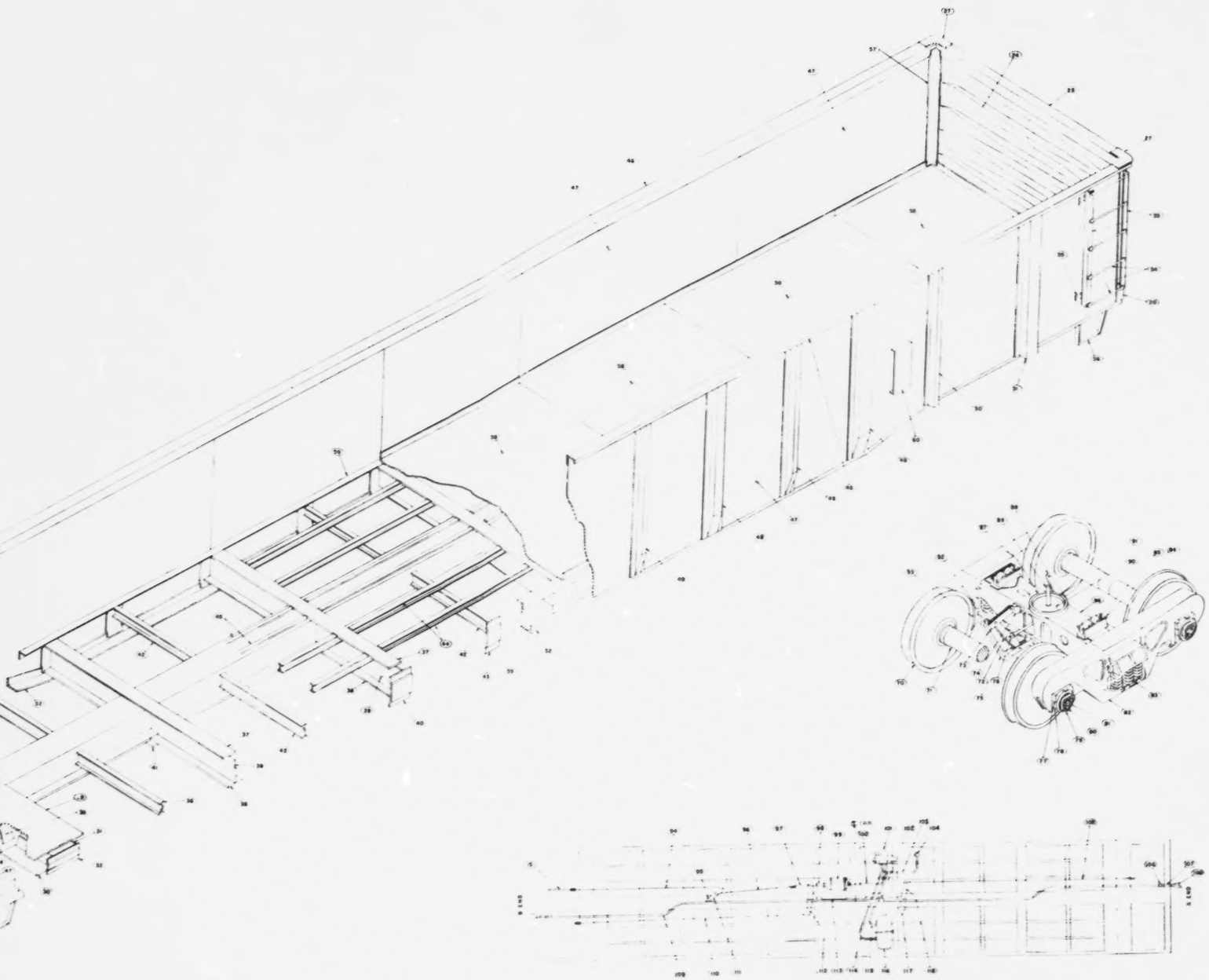


Figure 5.2

GONDOLA CAR CHART

100 Ton Capacity

1. Center sill
2. Combiner body bolster center filler and rear draft gear stop
3. Coupler yoke
4. Draft gear
5. Draft gear follower
6. Combined striking casting and front draft gear stop
7. Coupler head
8. Coupler knuckle
9. Draft gear carrier
10. Draft key
11. Angle cock support
12. Angle cock "U" bolt
13. Hand brake gear housing
14. Hand brake wheel or lever
15. Hand brake chain
16. Hand brake sheave and support
17. Brake step
18. Uncoupling rod bracket
19. Uncoupling rod
20. Bottom corner band
21. End ladder stiles
22. End ladder tread
23. End ladder stile bracket
24. Steel end
25. End top plate
26. End still
27. Top corner tie
28. End and center sill connection
29. Bolster top cover plate
30. Bolster bottom cover plate
31. Bolster web plate
32. Bolster and side connection
33. Bolster sole plate
34. Body side bearing
35. Body side bearing reinforcement
36. Crosstie at wheel
37. Crossbearer top cover plate
38. Crossbearer bottom cover plate
39. Crossbearer web plate
40. Crossbearer side connection
41. Crossbearer tie plate
42. Intermediate crosstie
43. Crosstie side connection
44. Floor stringer
45. Center sill filler bar
46. Side top plate
47. Side sheet
48. Side post at crossbearer
49. Intermediate side post
50. Side post at wheel crosstie
51. Side post at bolster
52. Side sill
53. Side ladder stiles
54. Side ladder treads
55. Side ladder stile brackets
56. Sill step
57. Inside corner post
58. Floor sheet or decking
59. Floor support angle
60. ACI label support
61. Drop end locking mechanism
62. End sheet--inside
63. Lifting loop
64. Floor closing angle
70. Wheel
71. Axle
72. Truck dead lever
73. Dead lever fulcrum
74. Dead lever fulcrum bracket
75. Brake beam
76. Bottom rod
77. Roller bearing adapter
78. Roller bearing assembly
79. End cap
80. End cap retaining bolt
81. Locking plate
82. Truck side frame
83. Truck springs
84. Truck side bearing
85. Side bearing roller
86. Truck bolster
87. Truck center plate cast integral with truck bolster
88. Truck live lever
89. Center pin
90. Horizontal wear plate
91. Vertical wear plate
92. Brake shoe key
93. Brake shoe
94. Handbrake rod (horizontal)
95. Jacking lever fulcrum
96. Brake rod
97. Hand brake chain at cylinder
98. Cylinder push rod
99. Brake cylinder
100. Brake cylinder pipe (3/4")
101. "ABD" control valve
102. Branch pipe tee
103. Retaining valve pipe (3/8")
104. Retaining valve
105. Top rod--"A" end
106. Brake pipe coupling
107. Brake pipe nipple
108. Angle cock (1 1/4")
109. Brake pipe (1 1/4")
110. Top rod--"B" end
111. Jacking lever
112. Cylinder lever
113. Brake adjuster (slack)
114. Auxiliary reservoir pipe (3/4")
115. Emergency reservoir pipe (3/4")
116. Comb. auxiliary and emergency reservoir
117. Floating lever fulcrum
118. Floating lever

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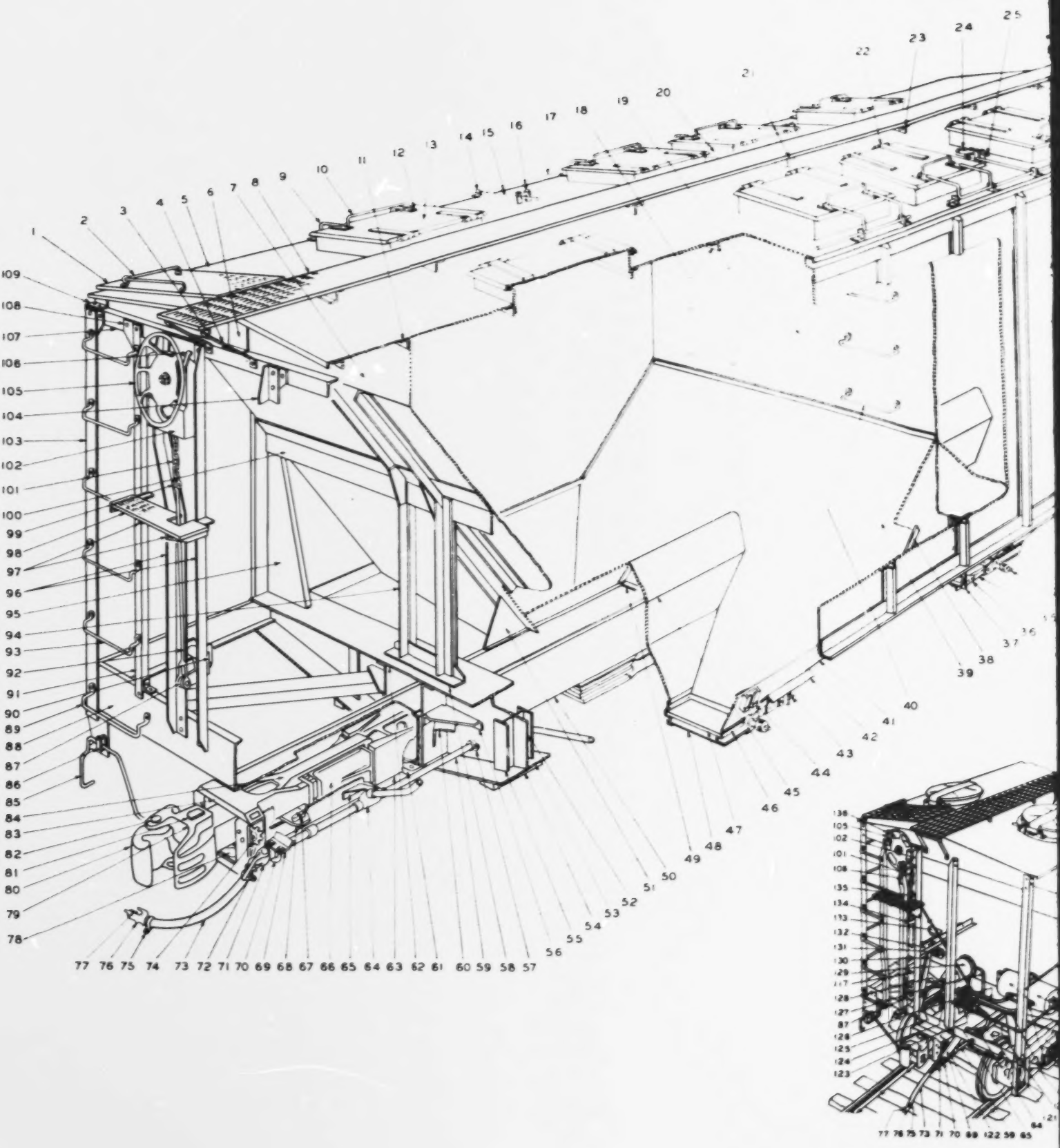

The Interstate Commerce Commission classifies the Covered Hopper Car as a Box or Other House Car. Interstate Commerce Commission Safety Appliance Standards for this car are required to conform with Safety Appliance Standards for Box or Other House Cars.

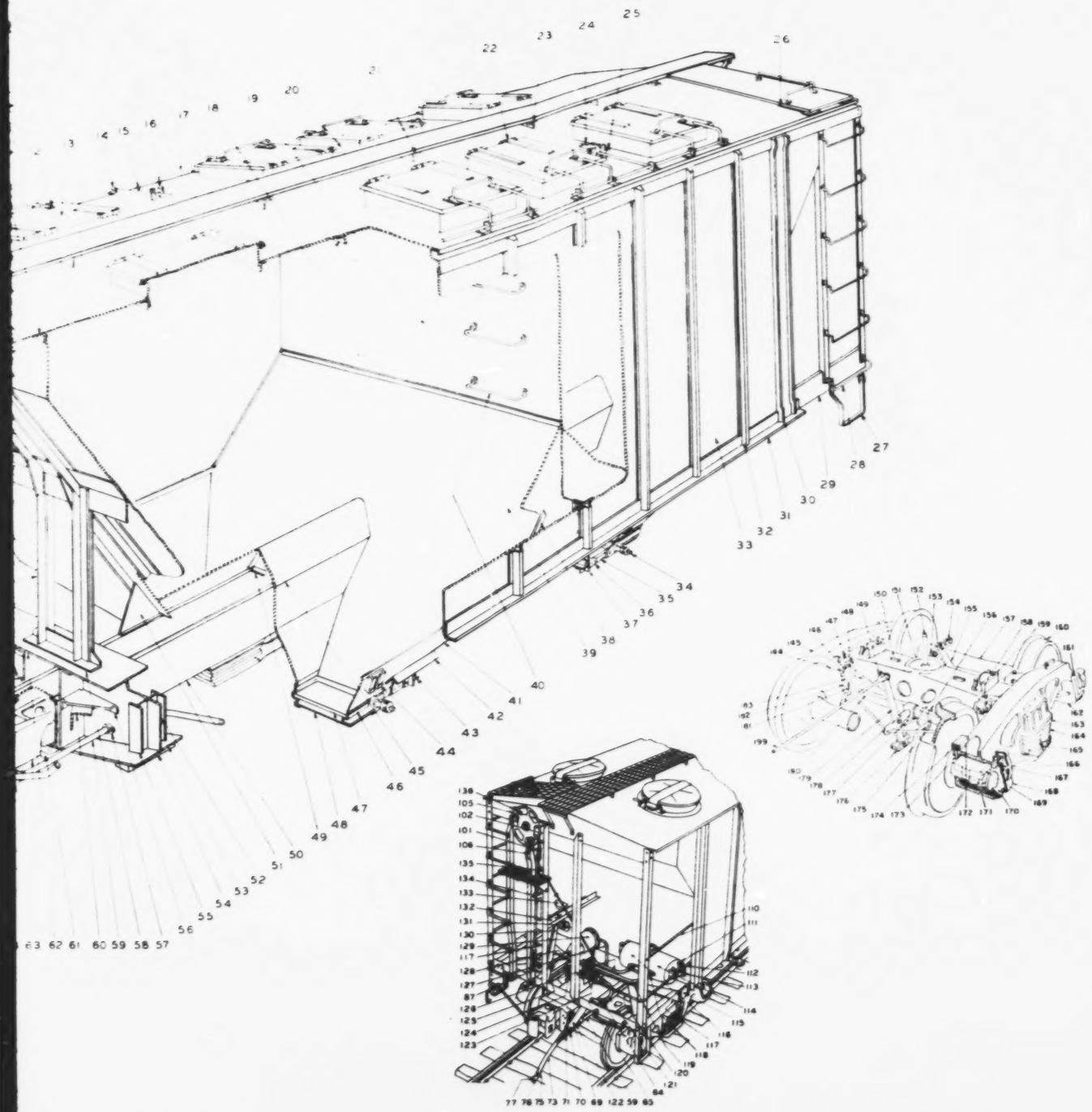

Figure 5.3

COVERED HOPPER CAR CHART

1. Latitudinal running board
2. Running board handhold (Roof handhold)
3. Running board end support
4. Longitudinal running board bracket
5. Roof sheet
6. Roof and end plate connection
7. End sheet
8. Longitudinal running board
9. Locking bar arm
10. Hatch cover handle
11. Roof and end sheet connection
12. Locking bar wear plate
13. Hatch cover
14. Locking bar bearing
15. Locking bar handle
16. Locking bar fastener
17. Locking bar rod
18. Roof carline
19. Center partition
20. Hatch frame
21. Running board intermediate saddle
22. Hatch cover hinge
23. Running board splice saddle
24. Seal pin chain
25. Seal pin
26. Latitudinal running board bracket
27. Sill step
28. Side ladder tread
29. Sub side sill
30. Bolster post (side post at bolster)
31. Side sill (angle)
32. Intermediate side post
33. Side sheet
34. Sliding door operating shaft
35. Sliding door guide
36. Door guide and support connection
37. Door guide support
38. Slope sheet and side sheet connection
39. Crossbridge slope sheet
40. Interior ladder tread
41. Outer slope sheet
42. Slope sheet stiffener
43. Sliding door stop
44. Vibrator bracket
45. Center sill hood
46. Outlet door frame
47. Sliding door
48. Bottom seal plate
49. Center sill hood stiffener
50. Center sill
51. End slope sheet and center sill gusset
52. Body bolster diaphragm
53. Body bolster bottom plate
54. Body side bearing
55. Side bearing brace
56. Diagonal brace bracket
57. Brake pipe clamp
58. End slope sheet support connection on bolster
59. Brake pipe
60. Diagonal brace
61. Body center plate
62. Body bolster top cover plate
63. Rear draft gear stop, cast integral with body bolster center filler
64. Branch pipe tee
65. Branch pipe tee support
66. Draft gear
67. Draft key retainer
68. Draft key
69. Angle cock holder bracket
70. Angle cock U bolt
71. Angle cock
72. Air brake hose nipple
73. Air brake hose
74. Coupler height adjustment mechanism
75. Air brake hose clamp
76. Air brake hose coupling
77. Air brake hose coupling gasket
78. Coupler carrier and centering device
79. Coupler head
80. Coupler knuckle
81. Cap--Coupler top locklift hole
82. Coupler knuckle pin
83. Combined striking casting and front draft gear stop
84. Coupler yoke
85. Uncoupling lever
86. Uncoupling lever bracket
87. Hand brake bell crank
88. End sill
89. End handhold
90. Hand brake bell crank bracket
91. End ladder stile
92. Vertical hand brake rod
93. End ladder tread
94. End slope sheet support
95. Bolster and bolster post gusset
96. Hand brake housing supports
97. Brake step bracket
98. Brake step
99. Hand brake winding chain clevis
100. End slope sheet stiffener
101. Hand brake winding chain
102. Hand brake gear housing
103. Corner post
104. End post
105. Hand brake wheel
106. Hand brake ratchet operating lever
107. End plate
108. Vertical angle and end plate connection
109. Top corner bracket
110. Side handhold (upper)
111. Air brake reservoir mounting bolt
112. Side handhold (lower)
113. Auxiliary reservoir support bracket
114. Auxiliary reservoir
115. Routing card holder
116. Emergency reservoir
117. Reservoir release rod
118. Pipe connector
119. Auxiliary reservoir pipe
120. End handhold (upper)
121. Branch pipe
122. Brake pipe nipple
123. Combined dirt collector and branch pipe cutout cock
124. "AB" valve
125. Cylinder lever guide
126. Emergency reservoir pipe
127. Brake cylinder pipe
128. Brake cylinder push rod
129. Brake cylinder
130. Cylinder lever
131. Brake lever badge plate
132. Cylinder lever fulcrum support
133. Defect cart receptacle
134. Top end brake rod guide
135. Release control retainer pipe (Retainer pipe)
136. Release control retainer (Retaining valve)
144. Brake shoe key
145. Truck side frame
146. Brake hanger wear plate
147. Brake hanger key
148. Brake hanger braker, cast integral with side frame
149. Brake pin and cotter
150. Truck bolster
151. Truck center plate, cast integral with truck bolster
152. Center pin
153. Dead lever guide braket
154. Dead lever guide
155. Dead truck lever
156. Bottom rod safety support
157. Axle
158. Truck side bearing roller
159. Truck side bearing and roller guide
160. Wheel
161. Journal box lid pin
162. Journal box, cast integral with truck side frame
163. Top spring plate
164. Truck spring
165. Bottom spring plate
166. Journal box lid hood
167. Journal box lid spring
168. Journal box lid
169. Journal bearing wedge
170. Journal packing waste
171. Journal bearing or journal brass
172. Dust guard cap
173. Dust guard
174. Dust guard wedge or plug
175. Brake beam truss rod
176. Bottom brake rod
177. Brake beam safety support
178. Brake beam strut
179. Live truck lever
180. Brake beam compression member
181. Brake hanger or brake beam hanger
182. Brake shoe
183. Brake head
184. Floating and truck lever connecting rod

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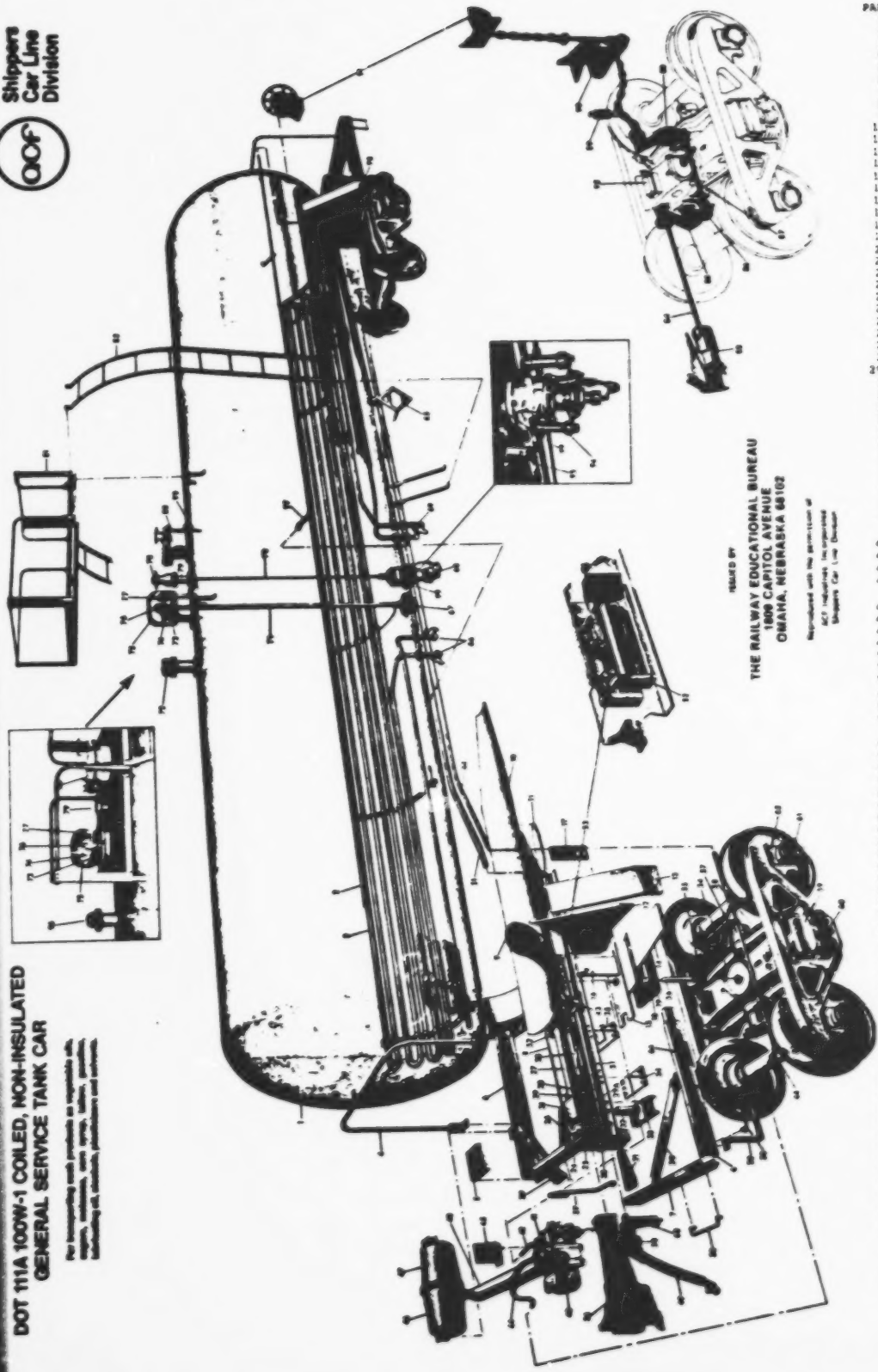
Figure 5.4

GENERAL SERVICE TANK CARS

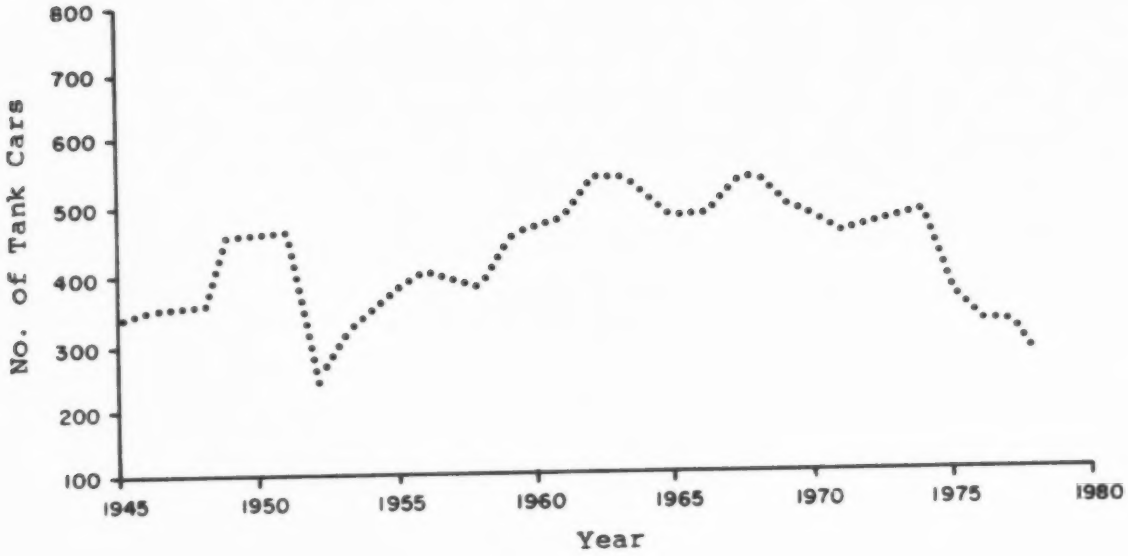


PARTS LIST

1. Tank
2. Side safety rail
3. Interior heater coils
4. End safety rail
5. End platform grating
6. Side sill
7. End sill
8. Stub draft sill
9. Tank cradle
10. Cradle pad
11. Cradle pad reinforcement
12. Bolster web
13. Bolster end cover
14. Bolster bottom cover
15. Draft sill bottom cover
16. Front side bearing brace
17. Rear side bearing brace
18. Body centre plate
19. Body side bearing
20. Side and end sill brace
21. End sill gusset
22. Sill step
23. Grab iron
24. Striker
25. Striker flange
26. Striker reinforcement
27. Coupler yoke
28. Draft gear
29. Front draft lug
29A. Front draft lug reinforcement
30. Front follower block
31. Coupler pin top wear plate
32. Coupler pin
33. Support assembly--Coupler yoke pin
34. Safety strap
35. Draft gear carrier assembly
36. Coupler--Type "F"
37. Uncoupling rod
38. Coupler carrier
39. Uncoupling rod bracket assembly
40. AB valve
41. Combined dirt collector and branch pipe cut-out cock
42. Branch pipe
43. Branch pipe tee
44. Brake cylinder pipe
45. Retaining valve (Piping to AB valve not shown)
46. Auxiliary reservoir
47. Emergency reservoir
48. Release rod
49. Train line hose
50. Angle cock
51. Train line
52. Rear draft lug (Back-stop)
53. Center filler assembly
54. Truck center bearing
55. Truck side bearing (See No. 92 for friction side bearing)
56. Center pin
57. Truck mounted brake
58. Brake beam
59. Truck bolster
60. Truck spring group
61. Roller bearing
62. Roller bearing adapter
63. End placard holder
64. Route card board
65. Side placard holder
66. Steam outlets
67. Sump
68. Bottom outlet valve assembly
69. Steam inlet
70. Bottom outlet valve rod
71. Education pipe
72. Safety relief valve
73. 1/4" needle angle valve
74. Vacuum relief valve
75. Housing
76. 2" ball valve (Siphon valve)
77. 1" ball valve (Air inlet valve)
78. Bottom outlet valve wrench
79. Bottom outlet valve rod nozzle
80. Manway nozzle
81. Operating platform
82. Side ladder
83. Hand brake pull rod clevis
84. Hand brake pull rod
85. Brake lever
86. Bottom connection safety strap
87. Bottom connection
88. Hand brake lever
89. Hand brake release spring
90. Ball crank
91. Hand brake
92. Friction side bearing
93. Outage gage
94. Steam jacketed bottom outlet ball valve
95. Operating handle
96. Safety vent (Not for flammable liquid service - see No. 72)
97. Side handrail support
98. Side handrail end support
99. Universal flange

Figure 5.5

TANK CARS OWNED OR LEASED BY RAILWAYS



Source: [51]

Since 1974 the continuing decrease is the result of several factors. Newer tank cars have higher capacities thereby reducing the number required. The increasing use of pipelines continues to reduce the need for tank cars.

5.2.5 Flatcars

The flatcar, as the name suggests, was originally just a flat wooden deck mounted on a steel frame on two-wheel truck assemblies. It was generally used to carry odd size cargo which would have difficulty fitting into enclosed or semi-enclosed freight cars.

Early flatcar designs have grown from a length of 52½ ft. to current lengths of 90 ft. capable of carrying two 40 ft. containers.

While much attention has been given to the ultra-high capacities and unusual body arrangements of many types of cars introduced over the past few years, these features have long

characterized many of the special flatcars. Capacities of up to 300 tons have been possible for some time in flatcars having special running gear arrangements. Other features have included depressed centres, well holes which can accommodate the tallest possible loads, and bodies which can be disassembled so as to simplify the loading or unloading of excessively large pieces of machinery.

The majority of flatcars are now used for carrying intermodal traffic. Container/Trailer-On-Flatcar (C/TOFC) applications are discussed more fully in section 5.3.

The configuration of a typical 90 ft., 65 ton capacity flatcar designed for C/TOFC operation is illustrated in Figure 5.6.

5.3 Current Trends

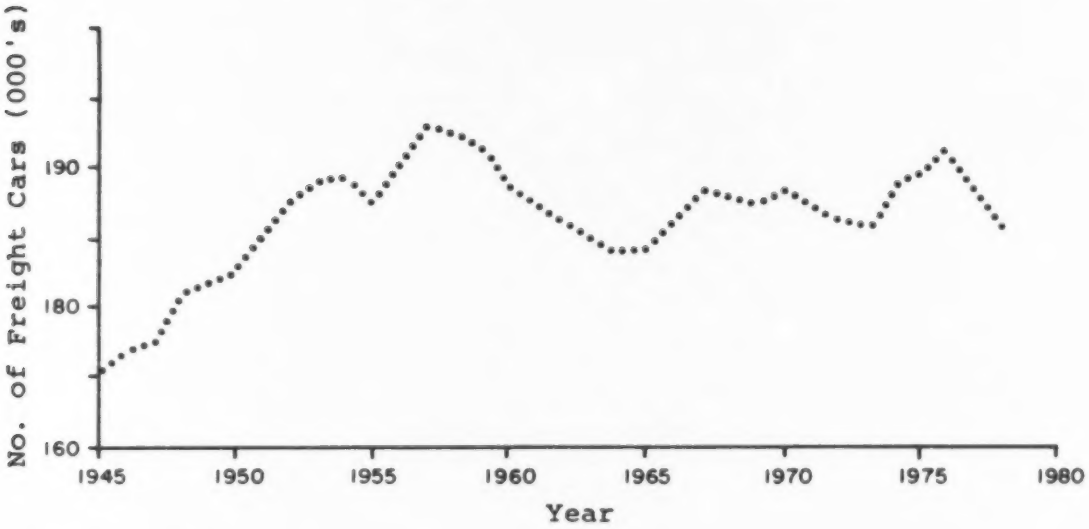
5.3.1 Statistical Review

Since 1945, the total number of cars in freight service in Canada has changed little. As shown in Figure 5.7, the total number of freight cars increased by only 17.3%, from 164 769 in 1945 to 193 325 in 1976. This total has since decreased to 182 138 in 1978. With the notable exception of the box car, the number of most individual car types have been increasing slowly (see Table 5.1).

Box car numbers have decreased from 99 904 in 1971 to 80 676 in 1978, a decrease of 19% in seven years. This is due to increasing use of TOFC/COFC and other purpose built cars. Freight cars are now being built for specific commodities, whereas in the past the commodities to be transported were required to fit into the freight cars available at that time. One example of such a change is the automobile tri-level car. Automobiles which were previously carried in box cars are now loaded onto special three level carriers. The disadvantage of purpose-built freight cars is that they generally run empty from destination to loading point. An example of this is the movement of coal from inland B.C. and Alberta to west coast ports.

Figure 5.7

FREIGHT CARS IN SERVICE 1945-1978



Source: [51]

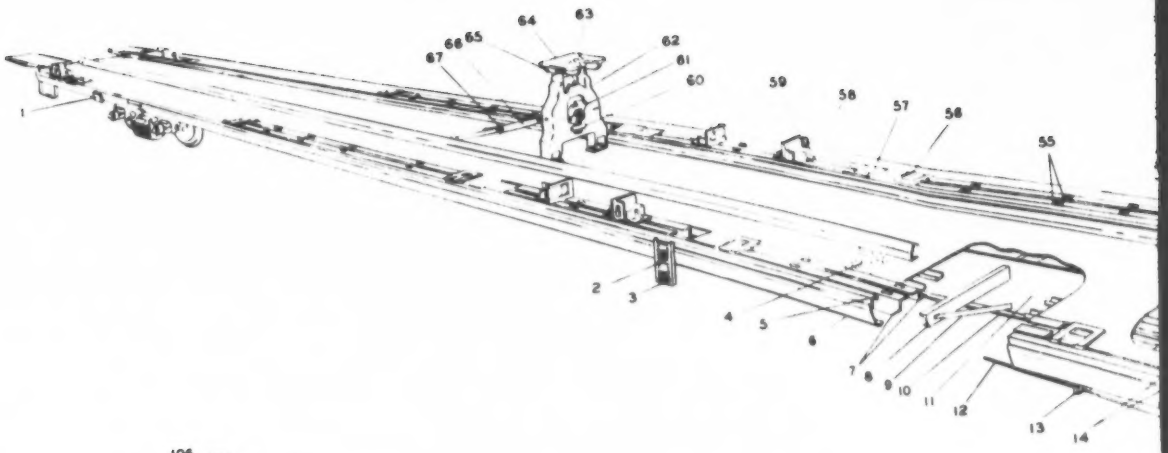
Figure 5.8 shows that this situation has not significantly affected the percentage of empty haul. For any given year between 1969 and 1978, the empty freight car miles represent approximately 40% of the total.

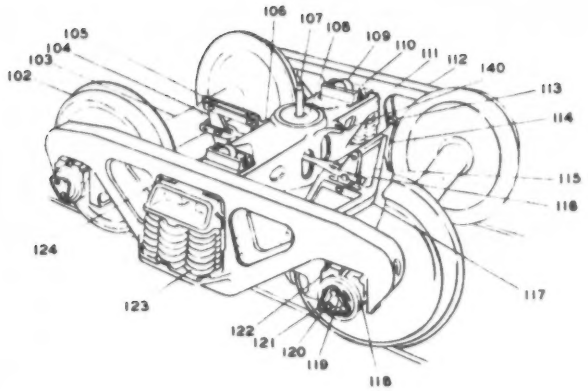
Through the use of high-strength steels and by optimizing steel placement, freight car capacity has been increasing steadily. Essentially this is now a process of trading off freight car tare weight, for increased payload, rather than increasing gross weight since axle loadings have now reached their maximum. This is illustrated graphically in Figure 5.9.

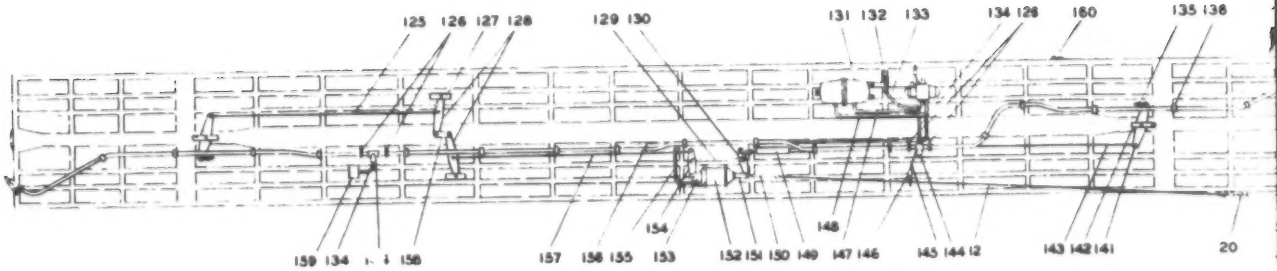
Although the total number of freight cars has changed very little, the tonnage carried has nearly doubled between 1961 and 1978 (see Figure 5.10). This increase primarily reflects increased car capacities since freight car miles and utilization have not increased greatly.

5.3.2 Box Cars

Box cars are now primarily employed to transport valuable commodities and products requiring protection from weather or against breakage. Besides the plain type of box car intended for ordinary freight traffic, there are box cars made to accommodate the products peculiar to certain industries such as automobile parts, lumber, grocery products, appliances, and some bulk materials [49].







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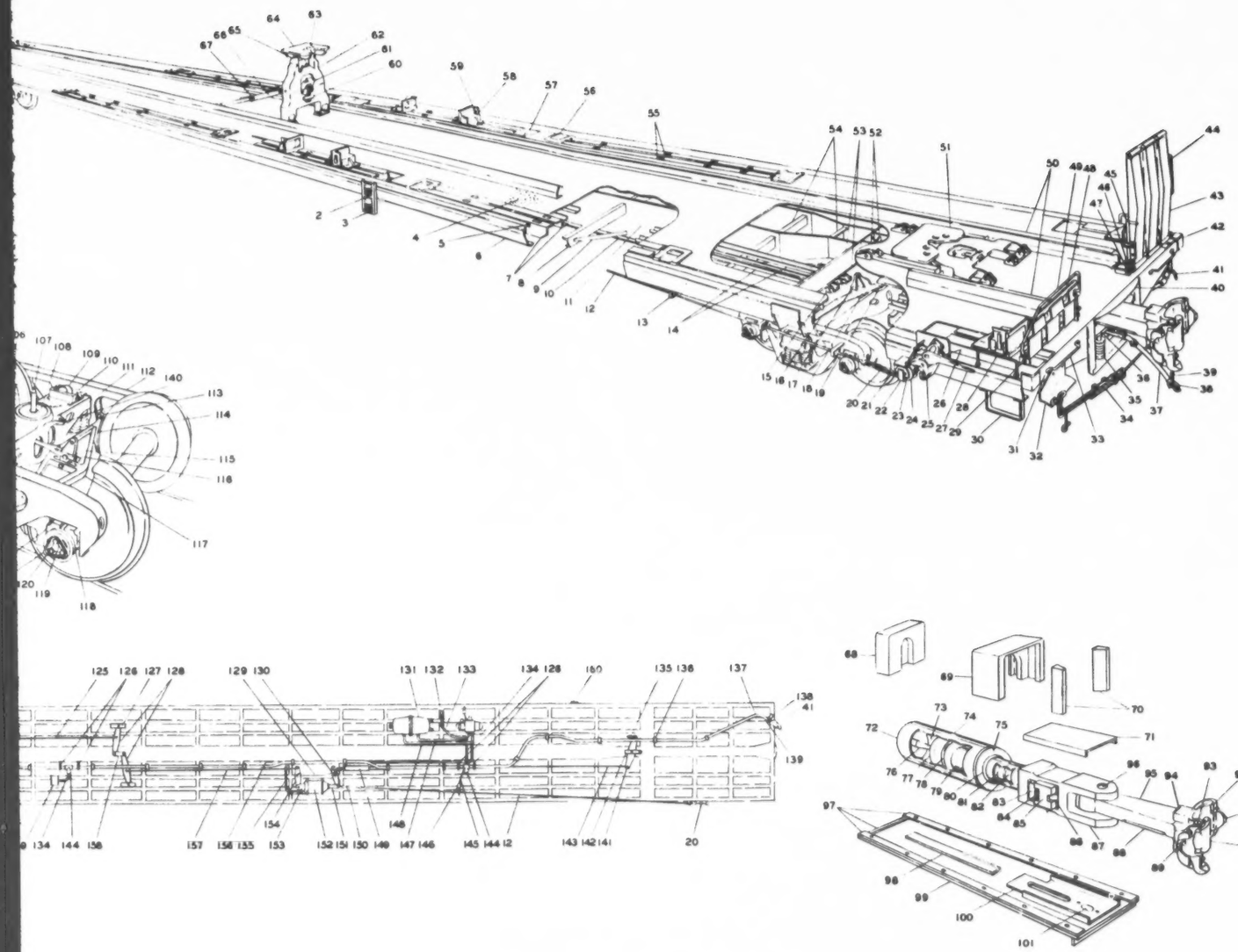

Figure 5.6

ALL-PURPOSE FLATCAR
TTX TOFC/COFC Design

1. Routing card board
2. ACI label
3. ACI label mounting bracket
4. Non-skid decking paint
5. Side sill
6. Side sill reinforcement
7. Container pedestal track
8. Crossbearer
9. Crossbearer diagonal brace
10. Fabricated center sill bottom cover plate
11. Fabricated center sill web
12. Hand brake rod
13. Hand brake rod guide
14. Floor stringer
15. Stringer support bracket
16. Bolster bottom cover plate
17. Side bearing brace
18. Body side bearing
19. Body center plate
20. Hand brake chain
21. Hand brake mounting plate
22. Chain guard
23. Sheave wheel bracket
24. Sheave wheel
25. Hand brake gear housing
26. Hand brake release handle
27. Hand brake lever
28. Side handhold
29. Bridge plate hinge
30. Sill step
31. End sill
32. Uncoupling lever bracket
33. Horizontal end handhold
34. Telescoping uncoupling rod
35. Coupler carrier spring
36. Coupler carrier
37. Air brake hose
38. Air brake hose coupling
39. Air brake hose chain
40. Striker
41. Angle cock
42. Corner connection
43. Main bridge plate
44. Main bridge plate handhold
45. Bridge plate release pin
46. Release pin guide
47. Spring loaded bridge plate lock
48. Auxiliary bridge plate (offset)
49. Auxiliary bridge plate handhold
50. Inside rub rail
51. ACF Medel 4 retractable trailer hitch assembly (non-cushioned, tractor operated)
52. Bolster center filler
53. Bolster web
54. Center sill stiffener
55. Station slots for engaging pedestal lugs
56. Container pedestal (stored position)
57. Pedestal storage pocket
58. Retractable container pedestal (service position)
59. Automatic container lock
60. Trailer hitch pull-up bar
61. Knock-down bumper
62. Vertical strut
63. Kingpin locking jaws
64. Mounting plate
65. Jaw lock indicator
66. Diagonal strut
67. Strut lock indicator
68. Back stop casting
69. Rear follower block stop
70. Front follower block stop
71. Yoke top guide
72. ACF FREIGHT-SAVER F15 end-of-car cushion unit
73. Fluid chamber
74. Outer cylinder
75. Packing gland adapter
76. Metering pin
77. Inner cylinder bearing
78. Inner cylinder draft stop
79. Inner cylinder
80. Packing nut
81. Floating piston
82. Air chamber (return system)
83. Rear follower block
84. Rubber mat cushion
85. Front follower block
86. Pre-load plate
87. Yoke
88. Coupler wear plate
89. Coupler vertical alignment pocket
90. Coupler knuckle
91. Coupler vertical alignment lug
92. Type F coupler head
93. Coupler knuckle pin
94. Coupler horn
95. Coupler shank
96. Coupler pin
97. Filler bars
98. Cylinder support bar
99. Cushion unit bottom cover plate
100. Yoke bottom guide
101. Coupler pin access cover
102. Wheel
103. Axle
104. Truck dead lever
105. Dead lever fulcrum
106. Dead lever fulcrum bracket
107. Center pin
108. Truck center plate
109. Side bearing roller
110. Truck side bearing roller guide
111. Truck bolster
112. Truck side frame
113. Brake shoe key
114. Brake shoe
115. Truck live lever
116. Truck lever connection rod
117. Unit brake beam
118. Roller bearing assembly
119. Locking plate
120. End cap retaining bolt
121. End cap
122. Roller bearing adapter
123. Truck spring
124. Snubber friction shoe
125. Top rod--A end
126. Branch pipe tee anchor
127. Auxiliary lever fulcrum
128. Auxiliary lever
129. Cylinder lever connection rod
130. Cylinder lever
131. Combined auxiliary and emergency reservoir
132. Retainer valve
133. Retainer pipe--3/8"
134. Branch pipe--1"
135. Truck bolster lever clevise
136. Brake pipe anchor
137. Brake pipe--1 1/4" (Train line)
138. Angle cock bracket
139. Angle cock U bolt
140. Truck bolster lever fulcrum bracket (cast integral on truck bolster)
141. Truck bolster lever
142. Truck bolster lever fulcrum
143. Top rod--B end
144. Branch pipe tee
145. Release rod
146. Release rod guide
147. Auxiliary reservoir pipe--3/4"
148. Emergency reservoir pipe--3/4"
149. Automatic brake regulator
150. Push rod chain
151. Cylinder push rod
152. Brake cylinder
153. Floating lever fulcrum
154. Floating lever
155. Brake cylinder pipe
156. Brake lever badge plate
157. Auxiliary lever rod
158. Auxiliary lever link
159. Reduction relay valve
160. Defect card receptacle

Length 90 Feet
Capacity 130 000 Pounds

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Table 5.1

FREIGHT CARS IN SERVICE IN CANADA* 1974-1978

	Number	Capacity	
		Total	Average
		(Tons 2 000 lbs.)	
Automobile			
1974	2 617	171 390	65.9
1975	2 776	184 345	66.4
1976	3 465	231 416	66.8
1977	3 411	226 140	66.3
1978	3 570	237 551	66.5
Ballast			
1974	2 296	142 497	62.1
1975	2 199	137 497	62.5
1976	2 670	172 450	64.6
1977	2 652	175 010	66.0
1978	2 530	169 590	67.0
Box			
1974	95 538	4 895 704	51.2
1975	92 669	4 785 923	51.6
1976	88 644	4 618 624	52.1
1977	83 478	4 373 749	52.4
1978	80 676	5 259 007	52.3
Flat			
1974	24 898	1 632 396	65.6
1975	25 722	1 704 911	66.3
1976	26 305	1 779 376	67.6
1977	25 081	1 700 036	67.8
1978	24 562	1 686 352	68.7
Gondola			
1974	20 414	1 563 410	76.6
1975	21 370	1 670 667	78.2
1976	21 377	1 655 721	77.5
1977	20 291	1 570 796	77.4
1978	19 773	1 574 747	79.7

Table 5.1 (Cont'd)

	Number	Capacity	
		Total	Average
		(Tons 2 000 lbs.)	
Hopper			
1974	27 398	2 257 938	84.1
1975	29 287	2 464 290	84.1
1976	31 801	2 710 721	85.2
1977	33 387	2 869 372	86.0
1978	32 672	2 818 778	86.3
Ore			
1974	7 151	616 986	86.3
1975	7 731	676 768	87.5
1976	8 236	727 580	88.3
1977	8 661	770 980	89.0
1978	8 551	742 230	86.8
Refrigerator			
1974	4 772	285 592	59.8
1975	5 016	305 942	61.0
1976	4 898	300 232	61.3
1977	4 685	290 278	62.0
1978	4 591	270 130	58.8
Stock			
1974	2 463	110 948	45.0
1975	2 359	106 375	45.1
1976	2 093	94 845	45.3
1977	1 924	87 455	45.5
1978	1 734	79 045	45.6
Tank			
1974	494	25 831	52.3
1975	379	18 417	48.6
1976	325	16 935	52.1
1977	324	17 018	52.5
1978	268	15 170	56.6

Table 5.1 (Cont'd)

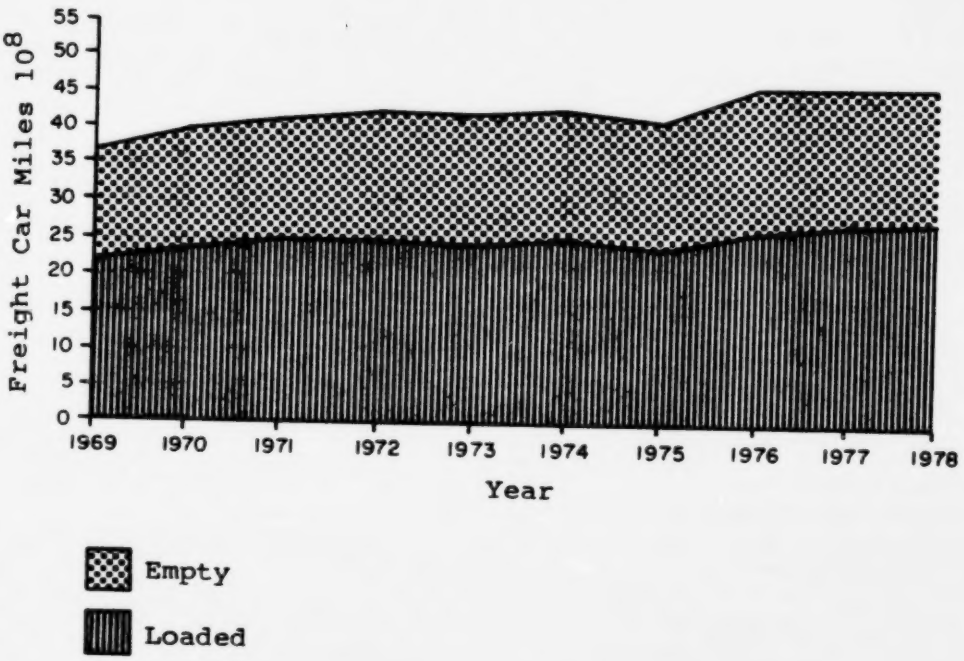
	Number	Capacity	
		Total	Average
		(Tons 2 000 lbs.)	
Other			
1974	2 851	151 750	53.2
1975	3 689	198 210	53.7
1976	3 511	188 976	53.8
1977	3 289	177 886	54.1
1978	3 211	173 846	54.1
Total			
1974	190 892	11 855 442	62.3
1975	193 197	12 253 345	63.4
1976	193 325	12 496 876	64.6
1977	187 183	12 258 720	65.5
1978	182 138	12 026 446	66.0

* Excludes privately owned railway cars.

Source: [51]

Figure 5.8

ANNUAL FREIGHT CAR MILES
HAULED, LOADED AND EMPTY
1969-1978



Source: [52]

Figure 5.9

AVERAGE FREIGHT CAR CAPACITY
1930-1978

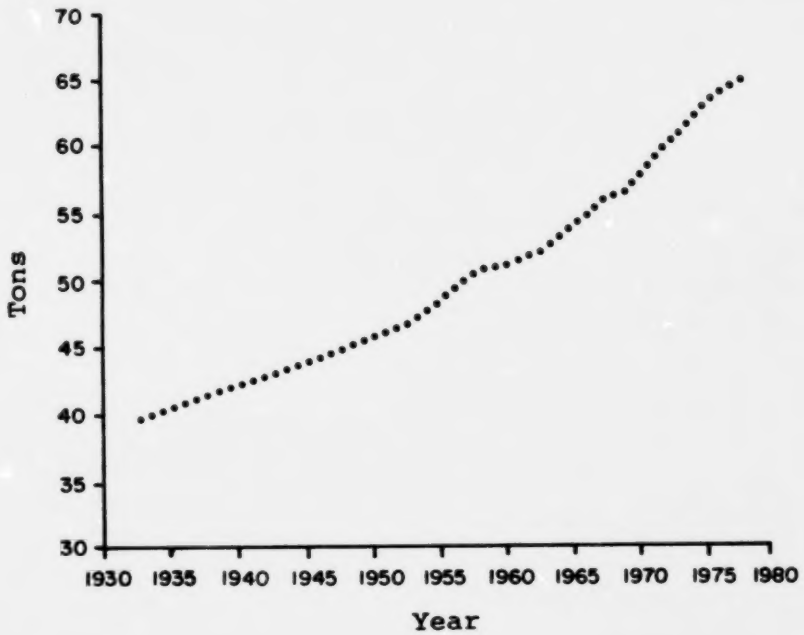
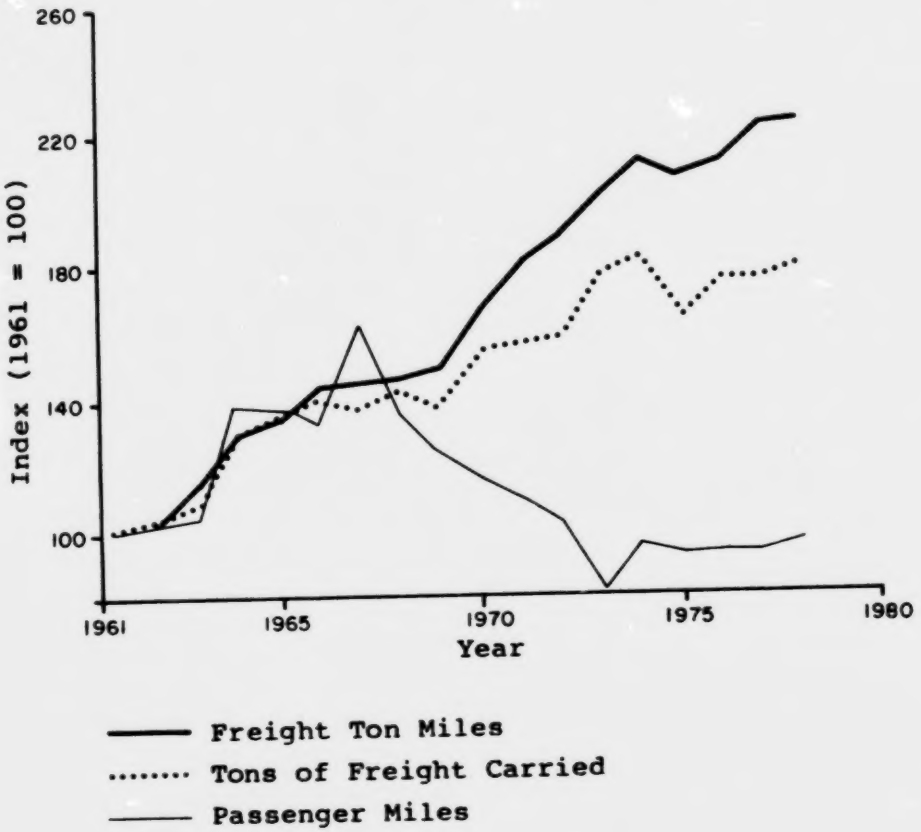


Figure 5.10

TRAFFIC TRENDS, COMMON CARRIER RAILWAYS
IN CANADA 1961-1978



Source: [52]

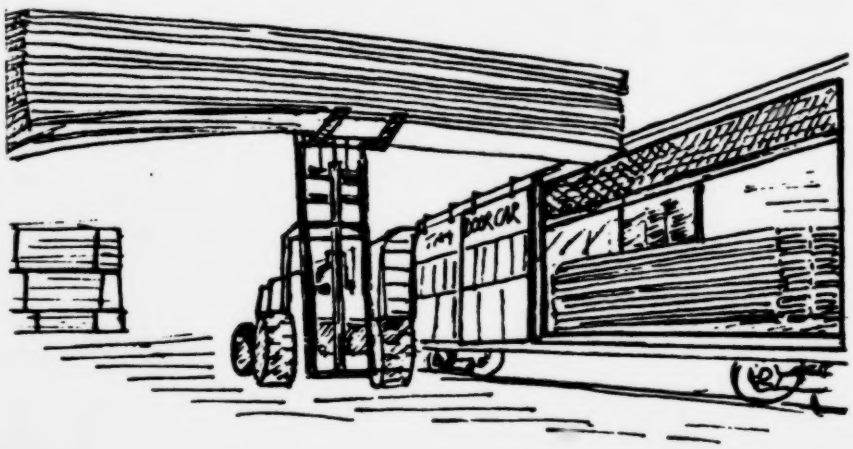
Recent innovations have included the use of sliding sill and end-of-car cushioning devices which are utilized in box cars hauling fragile commodities. These devices may consist of air bags or springs mounted inside the car to prevent damage should the cargo shift during shunting operations or due to slack action between the cars. Load retaining devices are more generally used to prevent cargo damage.

As materials handling has become more mechanized (through use of fork-lift trucks, conveyor belts, and so on), emphasis has been placed on effective door design. Cars with very wide doors, as much as half the car length, are particularly effective when loading/unloading large or long items such as lumber. The wide door box car helps decrease terminal time, as well as decreasing damage to lading during loading/unloading operations. Pictured below (Figure 5.11) is a typical wide door box car.

Today's high volume cars carrying low density merchandise may exceed 7 000 cubic feet, while weight capacities may be up to 100 tons. Tare weights are in the range of 20 tons.

Figure 5.11

WIDE DOOR BOX CAR



Wide 25 ft. door openings allow for fast loading/unloading of lumber and building products by lift truck.

Source: [56]

5.3.3 Gondola Cars

The basic gondola has fixed ends and a solid floor. However, industry has generated the need for purpose-built gondolas. The steel industry has encouraged the development of high capacity, high side cars to carry longer structural shapes, pipes and plates [49]. A large proportion of recent gondolas are of 100 ton capacity, with lengths of over 65 ft. The forest industry has generated the need for large volume cars to carry relatively low density material such as woodchips. Capacities may be in the order of 100 tons and over 7 000 cubic feet. These cars may be equipped for rotary dumping, or tip-up unloading. A 7 500 cubic foot or 100 ton capacity car is pictured in Figure 5.12 below, on a hydraulic hoist being dumped through an end door.

Figure 5.12

END DUMPING WOODCHIP GONDOLA

Source: [56]

Other innovations for forestry related gondola cars include lined interiors, and nets or lightweight hoods, to protect lading during transit.

Within the last few years, a concentrated effort was made by the Thrall Car Company to substantially improve the general-purpose gondola. Their latest product labelled the "railgon" was introduced in 1980. The new gondola actually uses approximately 8 000 [54] more pounds of steel than comparable

gondolas. Metal placement, as it relates to structural integrity, was of high priority during the design of the railgon. This effects a shift in design philosophy from increasing payloads to reduced maintenance costs.

The railgon has an inside length of 52½ ft., a volumetric capacity of 2 494 cubic feet, an empty weight of 71 000 lbs. and a payload capacity of 192 000 lbs. [54].

Features of the state-of-the-art gondola car include:

a) strategic components of the car bodies, strengthened to reduce repair requirements to areas traditionally requiring high maintenance;

b) pin connections at some points in the car body, to distribute forces which are often associated with damage in rigid structures;

c) ladder rungs structurally protected from damage; and

d) a white interior, more visible to crane operators to prevent damage during loading.

The coal industry has provided much of the impetus for improvement in gondola coal-car design. The most noticeable innovation is the low-slung belly section, which provides more loading space (usually in the order of four to six tons) by means of lowering the car floor between the wheel trucks. This means fewer cars may be used in a typical unit train, which in turn allows for lower initial costs and lower total maintenance costs. Further, the low-slung belly section effectively lowers the centre of gravity, which increases stability, hence reducing wear and again reducing maintenance costs.

The cars would typically be unloaded by a rotary dumper which physically turns the car over to empty it at the unloading station.

5.3.4 Hopper Cars

A hopper car is similar to a gondola car with the addition of doors in the floor of the car that may be operated to unload the cargo from below.

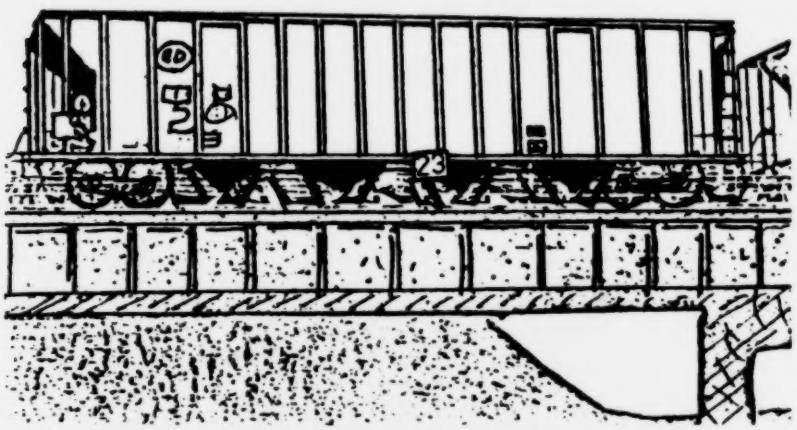
Open-top hopper cars are used most extensively in the movement of coal. Other high density commodities which move in these self unloading cars include stone, ballast and ore. When built with high-cube bodies, the cars are used for movement of low-density materials such as coke, sawdust and wood chips. Except when designed for extremely low-density ladings, these cars now are almost always built in 100 ton payload capacities. The growing use of such cars in unit trains has led to the

development of powered door operating arrangements, some of which are completely automatic. Such arrangements allow trains to increase the utilization of the cars [49]. The long term future of hopper cars in unit coal train applications is uncertain due to the development of slurry pipelines as an alternate transport mode. The relative economies may force a decline in the number of hopper cars in coal service.

Figure 5.13 below shows an example of a modern hopper car used in an automatic unloading unit train operation. It has a 100 ton, 3 750 cubic foot capacity and the capability of emptying a full load in 13 seconds or less. Unloading is initiated with shoe-pickup of DC current at trackside. This power actuates a pneumatic valve, allowing air under pressure to enter a large cylinder, which drives a mechanism that unlocks and forces open 16 discharge doors. This feature is important if coal must be dumped at cold ambient temperatures [56].

Figure 5.13

100-TON AUTOMATIC DISCHARGE COAL CAR



Source: [56]

5.3.5 Tank Cars

Most tank cars are now manufactured in the 100 ton, 30 000 gallon range, with only a limited number of larger units. The majority are built using the tank itself as an integral part of the structure, rather than using a separate frame to transmit longitudinal draft and buffing forces. This

Figure 5.14

PROCOR DUALFLOW TANK CAR

Source: [49]

reduces tare weight by eliminating the frame sills used in the past. To reach capacities as high as 60 000 gallons, some tank cars are mounted on pairs of six-wheel trucks or on a pair of four-wheel trucks at each end of the car.

Tank cars carry a full range of petroleum products, chemicals, vegetable and fish oils, fruit juices, syrups, liquid animal feed, etc. A Canadian manufacturer, Procor of Oakville, Ontario, fabricates a unique "dual-flow" car. This car, can be unloaded by either pressure discharge or air assisted gravity discharge. It has a capacity of 100 tons, and will operate at a pressure of up to 30 psi.

Other variations of this include the "Tank-Train" produced by General American. As many as 40 tank cars are linked as a unit with a flexible filler pipe joining each car to the next. The cars can then be loaded and unloaded from a single point rather than moving the train to load or unload each car. This system allows liquids to be loaded at 3 000 (U.S.) gallons per minute using a safer, cleaner "closed" system. Users of the "Tank-Train" concept in the United States have reduced handling costs by as much as 50% [58].

5.3.6 Flatcars

Bulkhead type flatcars (with a bulkhead wall or posts at each end) are used to transport forestry products such as pulpwood, plywood and plasterboard, or manufactured products such as steel pipe, poles and coils. Flatcars can be fitted with covered hoods, similar to covered gondola cars, for the shipping of steel coil. Stake-equipped flatcars, of lengths up to 90 ft., are used to carry long logs or poles. One such car is pictured in Figure 5.15 below. This 100 ton capacity unit is designed to carry over four truckloads of tree length lumber.

For extremely heavy loads, specially built 16-axle flatcars are used. The bed of the flatcar hangs down between two eight-axle trucks and can carry up to 880 000 lbs.

Another car used to transport extremely heavy loads is the "Schnabel" or transformer car. This car is comprised of two separable interlocking units which form a car body. The units are separated, and the load is interposed between and locked in place to form a complete transportation unit. They are used for moving transformers, and have capacities in the 1 000 000 pound range.

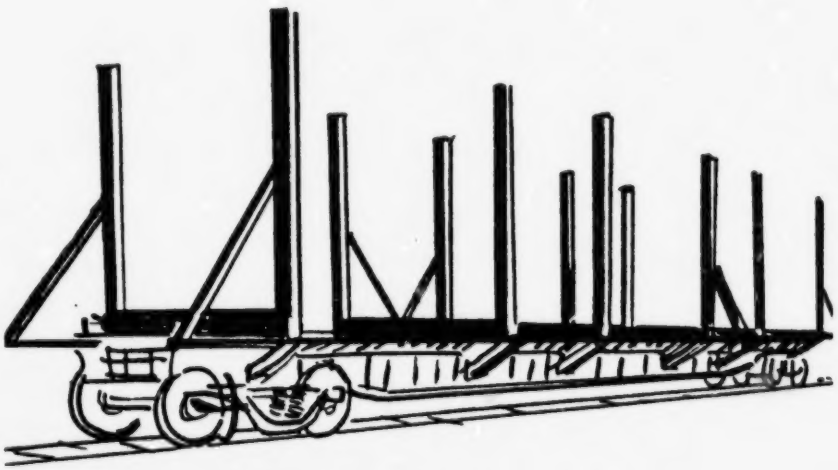
5.3.7 European Developments

In Europe, railroads are used extensively to carry high value products in fast "manifest freight" operations which compete with trucking over the short distances generally travelled. The most recent developments in freight cars which

are applicable to North American cars, are improvements in box car door design to speed loading and unloading, thus reducing terminal time.

Figure 5.15

LONGWOOD/LOG FLATCAR



Source: [56]

An Italian manufacturer, Costanasnaga, has designed a car with a retractable covering, such that there are no obstructions to hinder loading [59]. The sides and rounded roof are a metal frame covered by fabric. The metal frame retracts from one end, moving toward the other end, causing the fabric to crease and fold up, creating a large opening. With soft sides and roof, this is a light car suitable for handling bulky goods such as machinery. It has a volumetric capacity of about 5 000 cubic feet.

Wagonfabrik Verdingen has designed and produced a 70 ft. long car for use between Britain and the Continent [59]. It has two sliding doors per side, which give a clear width of 33 ft. when open. Vertical clearance is sufficient, and the floor is strong enough (the floor can take wheel loads of up to 5.5 tons) that large lift trucks can load goods directly into the car. Securing eyes are fixed to the underframe, sidewalls and roof. Hence, goods of any configuration can be securely lashed down.

A car built by Linke-Hofman-Busch, for transporting coils of sheet metal, utilizes a unique telescopic roof/wall system [59]. Three hoods, each, one third the length of the car, serve as the roof and walls. The middle and front hoods can be rolled back so that they both fit glove-like inside the rear hood, leaving the front two thirds of the car exposed. Thus, forklifts or cranes have easy access to the cargo.

5.3.8 Aerodynamics

Energy conservation has brought into focus the need to reduce aerodynamic drag of freight cars. At 100 kph, aerodynamic resistance consumes .04 gallons (U.S.) per car mile [28]. Wind tunnel testing is now being carried out which will lead to full scale testing of freight car units. The wind tunnel tests have shown the worst offenders to be empty flatcars and open topped hopper cars. These units cause considerable wind resistance due to the open air gap they form between other cars when placed in the middle of a train. The air turbulence created by this gap is responsible for the increased drag.

5.4 Selected Intermodal Developments

5.4.1 Articulated Flatcars

Articulated flatcars are purpose-built for carrying trailers or containers. The cars are kept together in sets of up to 10 units with each pair of units in the group sharing one common set of wheels. This substantially reduces tare weight by reducing the number of wheel truck assemblies by one half for the articulated car set. This concept was pioneered by the Sante Fe Railroad in 1977. It operated a set of six articulated single-trailer/container cars, a pilot project [60]. The cars were designed to handle 40 or 45 ft. containers or trailers. The concept, known to the industry as the "Six-Pack", proved to be successful and Sante Fe started putting the units into groups of 10, or "Ten-Packs". The ten-packs have now been in revenue service between Chicago and Los Angeles (a high speed route) since 1978 [61]. On this route, the articulated cars have reduced locomotive fuel consumption by 6 000 gallons (U.S.) per round trip when compared with standard flatcars. This represents a saving of as much as 300 000 gallons (U.S.) of diesel fuel per year, for a single train in regular service [62]. A second advantage claimed by the railroad is reduced wheel and rail head wear.

A similar concept, with a few additional refinements, is currently being developed by the Budd Carr Company. Designated the "Lo-Pac 2000", it is a multi-unit, articulated design capable of handling containers (up to 40 feet in length) or trailers (up to 45 feet in length), with nose or bottom-mounted refrigeration units. When loaded with a 13½ foot high trailer, the depressed loading area (or well) ensures that the top of the trailer will be no more than 14 feet, 7 inches above the top of the rail. When loaded on a normal flatcar, the top of the same trailer would be about 16 feet, 2 inches above the top of the rail. The lower profile reduces overhead clearance problems on some rail lines and improves fuel economy with reduced wind resistance. These cars went into revenue service in November, 1980 between New York and Chicago [63].

The future of these concepts will depend on the reliability and maintenance record of the units. Since the 10

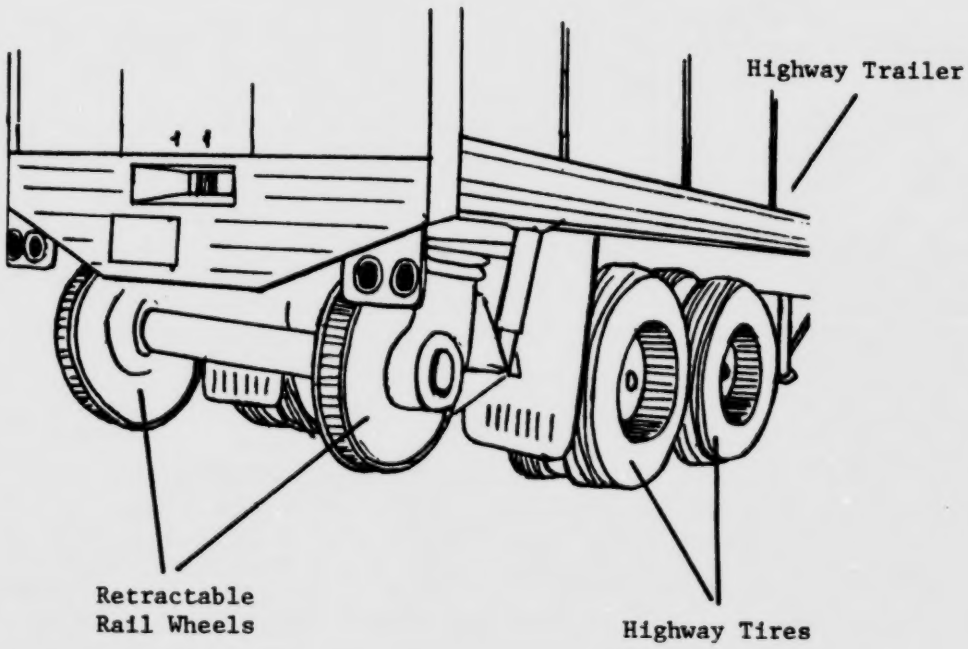
cars in a set form one unit, a problem in any one of the cars means removing the entire set from service, unless some convenient means of separating the units can be developed.

5.4.2 Roadrailer

The roadrailer pictured in Figure 5.16, is a highway van semi-trailer with a set of retractable railway wheels mounted at the rear. With the rail wheels in the lowered position, the highway wheels are lifted off the ground and the unit may be pulled on railway tracks by a locomotive. In the near future trains made up of 40 to 50 of these units will be pulled by one locomotive and 80 or more units will be pulled by two locomotives. A 50-unit train has recently been tested in operation between Alexandria, Virginia and Jacksonville, Florida. The 75-day program started in October 1980 and was carried out under the supervision of the Federal Railroad Administration [64]. Three hundred and fifty of these units were manufactured in 1980 as a joint effort between the Bi-Modal Corporation and the North American Car Corporation [61].

Figure 5.16

ROADRAILER



Source: [65]

This is not the first project to be undertaken. The Chesapeake and Ohio operated a fleet of 80 rail/highway vehicles for 10 years beginning in 1959. The vehicles were used to haul mail in express passenger trains, but were phased out as passenger services declined. Soon after, British Rail tested 50 rail/highway vans adapted from the C and O design. The project was haulted due to railroad-trucker jurisdictional disputes [65].

The incentives to develop the roadrailer include reduced energy and capital requirements. When in full revenue operation, it will move the same amount of freight as a conventional trailer-on-flatcar, using in the order of 40 to 50% less fuel. This is attributed to a number of factors, i.e., elimination of the flatcar, light weight (16 500 pounds empty, 59 500 pounds with maximum load) and lower wind resistance (because it rides directly on the rails) [66]. Taking unit cost ($33 000 per trailer), into account, the roadrailer will be approximately 25% less expensive for a railroad to operate than current trailer and piggyback car combinations, which require twice as many locomotives and more fuel [67].

The fuel savings are, as would be expected, greater when compared to conventional highway truck-trailers. Over a 1 000-mile highway trip, a typical truck-trailer would use 115 imperial gallons of fuel. Over the same distance a trailer-on-flatcar would use 76 imperial gallons and a roadrailer would use 43 imperial gallons, including additional fuel for local haulage to and from the railroad terminal. Roadrailer prototypes are currently running on both Canadian and United States railroads, but the major testing is being carried out in the United States.

Substantial savings will occur in terminal operations. Since the roadrailer is rolled in or out of a train, the transfer operation is done with truck tractors (which are needed to haul the trailer in any event) rather than expensive forklifts or gantry cranes. No switch engines or storage yards are needed. The roadrailer's mechanism performs the transfer between highway tires and rail wheels in less time than for a lifting operation [63]. The 45 ft. trailer has 12% more volume capacity than the conventional 40 ft. piggyback unit. It substantially reduces the capital investment required to purchase flatcars for carrying the units.

There are some disadvantages to this form of bi-modal operation. From the trucking standpoint, the added weight of rail gear will decrease the payload capacity available within the total gross vehicle weight limitations for the highway segment of the trip. From the rail standpoint, the roadrailer may not possess the structural integrity of conventional rail cars. Over time their failure rate may be higher. Trailer and container-on-flatcar services will still remain dominant if for no other reason than because of the large number of flatcars and piggyback trailers now in service, which require flatcars. Roll-

on, roll-off traffic in international shipping, for example, will continue to generate a demand for trailer-on-flatcar service.

Marine containers can also be used on roadrailers where the container is lifted on or off a roadrailer chassis. This however defeats one of the inherent advantages of the roadrailer, which is to reduce terminal handling requirements.

The Bi-Modal Corporation which manufactures this unit predicts that within 20 years, 25% of all railroad freight equipment in the United States will be roadrailers.

5.4.3 Two-Level C/TOFC Carriers

Two United States railroads are now testing flatcars capable of stacking trailers or containers in a two-high configuration on the flatcar. One unit built by Trailer Train and being run on a test basis by Union Pacific, is a lightweight, double platform trailer-on-flatcar prototype. The car mounted on two single axles, is limited to a 33 ft. length. This is considered the maximum length for a car having axle trucks which do not rotate as the car goes around a curve in the track. These simplified axle truck assemblies are used to reduce tare weight relative to a conventional four-axle flatcar.

A second concept being tested by the Southern Pacific Railroad, is an articulated double-stack container carrier. This prototype can carry two 40 ft. boxes loaded two-high on an articulated flatcar. They are similar to those discussed in section 5.3.1.

Both concepts promise reduced tare weight for a given number of trailers and containers but have some inherent disadvantages. Due to its greater height, the loaded flatcar will have more aerodynamic drag and cause clearance problems on some lines. With two containers, the unit is about the same height as a tri-level auto carrier. Terminal loading operations will also have to be carefully monitored to ensure that a heavy container is not loaded on top of a lighter one. This adversely effects the freight car dynamics as a result of the higher center of gravity.

5.4.4 Growth in C/TOFC Traffic

The growth in C/TOFC traffic is tied closely to the growth in international marine shipping, which in turn, relates to world economies. General cargo handled as bulk prior to 1970 is now almost exclusively shipped in containers. The shift to containerized traffic and the increasing number of sea/land transportation companies using "landbridges" instead of all sea routes, has emphasized the need for increased rail C/TOFC capacity. Single ships, unloading the equivalent of 1 000 twenty-foot containers in a 48-hour period are now common. In

the case of landbridge operations, all of this traffic is moved onward by rail to the final destination terminal. An extensive study on piggyback in the United States, forecasts growth rates of 10 to 12% per year to 1990. This is based on expected changes in level-of-service, fuel prices and intermodal co-operation [68]. In Canada, CN currently reports intermodal traffic growing at 15% per year compared to 5% for carload traffic [67].

5.5 Freight Car Trucks

The truck assembly connects the wheels to the car body or frame and allows the assembly to rotate relative to the car body as it negotiates a curve in the track. Figure 5.17 illustrates a typical truck assembly. Three-axle trucks are sometimes used for heavier loads.

As early as 1831, the four-wheel truck was introduced on the North American railway scene. Today, the four-wheel swivel truck continues to be the standard for practically all conventional freight cars and passenger cars, except for the heaviest loads. The four-wheel arrangement makes possible a low truck structure, a feature important in freight car design.

Two main drawbacks of this current design are:

a) the excessive wheel and rail wear caused by a set of four-wheels fixed firmly in the truck assembly as they travel around a curved section of track; and

b) the instability or "hunting" which occurs when lightly loaded cars are pulled at high speed.

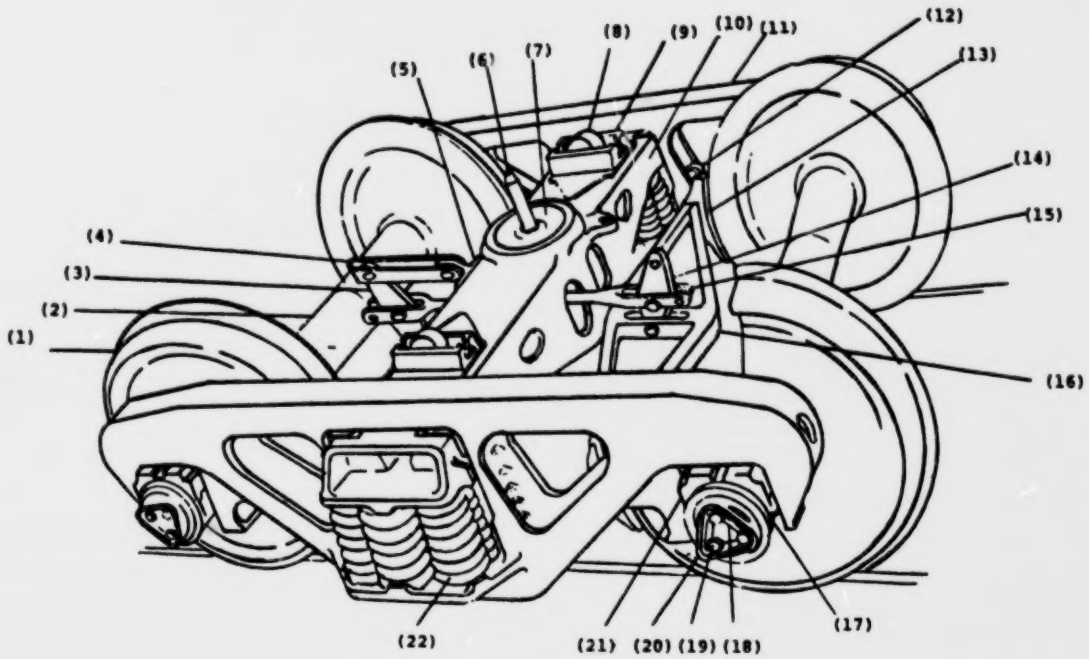
The first problem has lead to development of steering axle trucks.

Canadian National Rail Research, in co-operation with Railway Engineering Associates, Dominion Foundry and Steel Company, and Dressor Industries, has developed a self-steering truck (designated the DR-1), which is able to align its axles to the radius of the curve it is negotiating [88]. It also has increased hunting speed for light load service from 50 mph to 80 mph. Current freight car trucks negotiate curves in one of two ways. Rigid frame trucks maintain squareness and are "dragged" around curves. Parallelogramming trucks allow inter-axle lateral displacement (an improvement over rigid frame trucks). However, wheel and rail wear is still a major problem. Figure 5.18 illustrates the axle alignment of a parallelogramming truck negotiating a curve.

CN's self-steering truck, shown in Figure 5.19, allows for inter-axle displacement and rotation. Individual axles can align themselves with the centre of the curve such that at all times an axle and its wheels are travelling tangent to the curve.

Figure 5.17

TWO-AXLE FREIGHT CAR TRUCK



1. Wheel
2. Axle
3. Truck dead lever
4. Dead lever fulcrum
5. Dead lever fulcrum bracket
6. Center pin
7. Truck center plate
8. Side bearing roller
9. Truck side bearing roller guide
10. Truck bolster
11. Truck side frame
12. Brake shoe key
13. Brake shoe
14. Truck live lever
15. Truck lever connection rod
16. Unit brake beam
17. Roller bearing assembly
18. Locking plate
19. End cap retaining bolt
20. End cap
21. Roller bearing adapter
22. Spring

Source: [50]

Figure 5.18

PARALLELOGRAMMING TRUCK

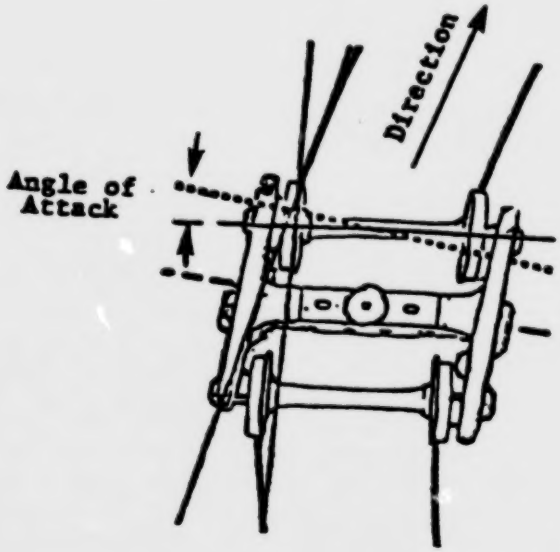
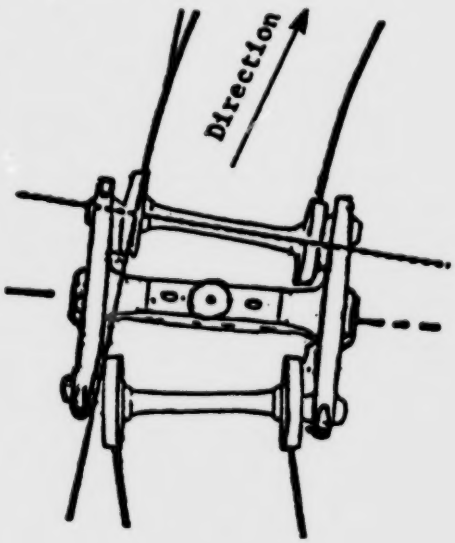


Figure 5.19

SELF-STEERING TRUCK



Source: [69]

This freight truck may be retrofitted to existing equipment. Its higher cost is offset by reduced wheel and rail wear and fuel consumption (due to lower rolling resistance on curves). A fleet of coal gondola cars is currently operating on the new trucks in Western Canada. It is estimated that wheel/rail wearing forces on curves have been reduced by some 60% [70].

The second problem, freight car instability or hunting under lightly loaded conditions, has led to various new developments. The Standard Car Truck Company has designed a system to enlarge the truck centre plate. The centre plate is identified on Figure 5.17. Known as the "centre plate extension system", this device reduces the tendency of the freight car to rock back and forth on the truck. The system is currently in use on Canadian Pacific's coal gondolas and 89 foot flatcars used in domestic container service.

Variable rate springs have also been developed by CP to reduce hunting. In a conventional spring system, an empty freight car rides on springs designed to support fully loaded cars. The rocking and vibrating stresses caused by the stiff springs may lead to early car component failure. The variable rate arrangement uses a set of standard springs in which more springs are used as the load increases. Hence, under light load conditions, few springs are used and the spring system is properly mated to the load which it must support. In general, wheel/truck design is an area of ongoing research. The overall objective of research in this area is to minimize rail wear, and metal fatigue in truck and car components by reducing dynamic loading.

5.6 Future Developments

Progress in materials research and the push for lighter freight cars will mean increasing the use of new materials such as aluminum, fibreglass and carbon fibre materials for car bodies. Although aluminum costs 40 to 50% more than steel, it has certain inherent advantages which make it attractive. Weight savings, in the order of 8 000 to 12 000 lbs. per car, result in less fuel consumed per unit of cargo moved. Aluminum freight cars also have a long service life of about 30 years, since they are highly resistant to corrosion. The scrap value of an aluminum car is about $12 000 compared to some $2 500 for a steel car. Currently there are about 8 000 aluminum bodied cars in North American service.

Fibreglass, carbon fibre materials, or other light weight materials, may prove to be useful in the development of high volume cars for low density lading. Weight savings in the order of 40% over a steel car and greater durability will be the key goals in car design [72].

Improvements will continue to be made in the area of wheel/rail dynamics, thereby reducing wheel and rail wear and the vibratory stresses that fatigue the car structures. They will include more wide spread use of steering axle trucks and articulated trucks for C/TOFC operations. Axle loads will remain at the 60 000 lb. level for many years to come as higher loads would require extensive changes to the track structure.

C/TOFC will likely be an area of intensive technological development to reduce costs, and to improve the level of service to make rail transport comparable with highway transport. The higher cost of energy will shift demand in favour of C/TOFC. Regulatory changes may also be implemented to encourage intermodal co-operation and development.

Very little research has been done on aerodynamics in the past. This will likely be an area of technological development, as there is an opportunity for fuel economy improvements which have not yet been exploited.

5.7 Summary

Freight car capacity has increased over the years to the current 100 ton capacity designs. With current axle loadings, future four-axle freight cars of 110 ton capacity are possible using lightweight materials and designs. More emphasis will be placed on increasing the volume capacity of cars in order to make low density cargo more profitable. Advances in loading/unloading methods have had the two-fold effect of decreasing terminal time and decreasing damage to cargo. Tip-up and rotary systems allow the unloading of certain bulk materials in relatively short periods of time. Unique door/cover arrangements ensure that cargo can be loaded/unloaded quickly and with minimal damage.

Intermodal transportation systems have decreased terminal time and cargo damage. Improvements are now directed towards increasing the level-of-service and fuel efficiency. To this end, articulated flatcars and roadrailers are the most significant developments. Both offer reduced tare weight and improved fuel economy. One outcome of these technologies may be a split of container and trailer traffic between articulated flatcars and roadrailers. Current flatcars are designed to carry both. The future of these developments will depend on the success of the current in-service testing.

Further fuel savings, as well as maintenance savings, will result from the use of self-steering trucks, particularly on rail lines where curvature is frequent and severe.

Chapter 6

TRAFFIC CONTROL SYSTEMS

6.1 Introduction

Chapter 6 follows the historical development of traffic control systems up to the present day and explains the concepts involved.

The British Columbia Railroad's centralized traffic control system is examined to illustrate the operation of a modern system. Application of automatic train control and the return of automatic car identification systems are discussed briefly as technologies for future implementation. Other specific future trends in traffic control are presented.

Traffic control systems will become very important in the future as a means of increasing line capacity without major capital expenditures.

6.2 Centralized Traffic Control (CTC)

6.2.1 General History of Development

Centralized Traffic Control (CTC) permits a relatively small number of train dispatchers to control train operations over a large territory from a single location. The world's first CTC system was installed on the New York Central Railroad in 1927. It controlled 40 miles of trackage [73]. The success of this system led to a steady growth in CTC development. CTC provided railroads with the opportunity to increase line capacity without resorting to such costly alternatives as double-tracking. As the quality of information processing equipment improved, the track sections falling under a single centralized traffic control centre grew to over 500 route miles.

Means of communicating with wayside detection equipment improved significantly with the introduction of microwave systems. The size of territories under CTC grew to the point where the dispatcher's clerical duties and not traffic duties became the limiting factor. Hence, new management information systems were introduced in order to assist dispatchers with such duties as assembling crew and train makeup information and maintaining the train sheet. A prime focus of computerization was in relieving dispatchers of clerical matters. Essential information was to be kept in an instantly retrievable form.

The first computerized CTC system was installed for the Union Railroad in 1966. This system performed only control, indication and a minimal amount of information recording functions. It did, however, demonstrate that the computer could ease the dispatcher's data recording duties [73].

By 1972, the minicomputer had increased in capability while shrinking in price. The expanded capabilities of the small computer, led engineers to search for additional ways to improve the CTC function. A major breakthrough occurred in 1973 with the installation of the first color video CTC system in Greenville, South Carolina. This new system utilized semi-graphic color video display units in place of the conventional wall panels to display the track diagram and status of the CTC territory [73].

Modern CTC centres control extensive operations, such as: automatic routing through the network, execution of meets and passes (which are dispatcher-planned with the computer tracking trains and clearing signals), and management of data systems integrated with the control software. Much of the data making up the information files are acquired automatically by the process control software as it monitors remote equipment and performs the requested control functions. These data files are supplemented with dispatcher inputs and filed as a basis for required reports. Both printed reports and responses to direct inquiry into these data files are provided [73].

Computerized CTC systems being installed today provide computer generated and displayed train sheets. Much of the data traffic movements are obtained automatically by the train tracking system. Supplementary data such as crew and consist information are entered by the dispatcher into the information system. The use of stored forms and "fill in the blanks" techniques both simplifies recording and checks the entries for validity. Since the sheet is stored in computer memory, it can be accessed and displayed, as required, by both operations and management personnel.

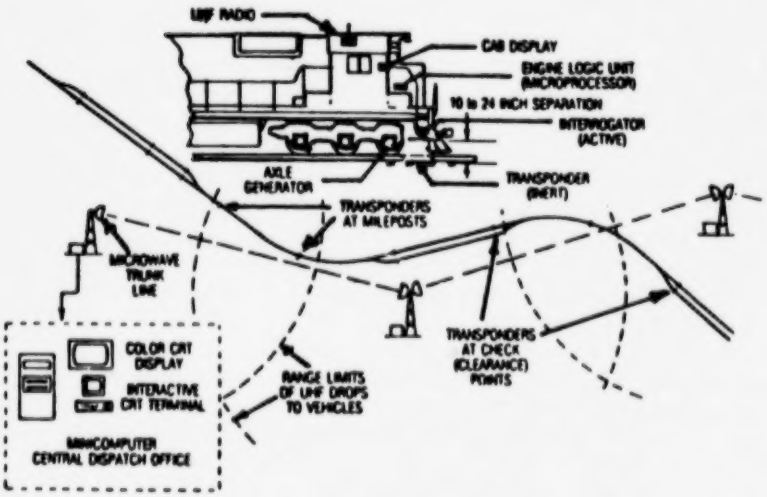
At the highest level of computerization, systems can calculate estimated train arrival times, plan routes, meets and passes to minimize train delays [75]. Movement may be handled without routine dispatcher inputs. When conflicts beyond the capability of the automatic mode must be handled, the dispatcher has an override option to take direct control of the situation.

6.2.2 British Columbia Railroad: A Canadian Application

A unique application of computerized CTC is being pioneered by the British Columbia Railroad. A relatively low-cost system, it is well adapted for operation on railways which have long stretches of unsignalled line. The basis of the system is the LIC (Location, Identification, Control) scheme. It is shown schematically in Figure 6.1 below.

Figure 6.1

LOCATION IDENTIFICATION CONTROL SYSTEM



Train passing-point identification is provided by the output of an interrogator mounted on the locomotive as it passes transponders located at mileposts. The interrogator sends out a 200 KHZ energizing field, providing power to the inert transponder. In turn, the transponder emits multiple repetitions of its individual, permanently-coded identification signal. The signal is received by the interrogator and is sent to the engine logic unit (mounted in the locomotive cab). The engine logic unit automatically sends the information via a microwave/UHF radio communications system to the computerized central control centre thereby locating the train on the system. The system continually keeps track of the whereabouts of every vehicle that has entered the controlled trackage, by integrating the distance it has travelled (as indicated by axle-generator output) since it passed the last transponder. All restrictive messages must be acknowledged by the engineer, and the continuity of the communications link to the central control is continuously verified. Central control therefore has an inherent train-control and overspeed supervisory capability, directly matched to the situation of each train at all times.

6.3 Automatic Train Control

Automatic Train Control (ATC) refers to any system designed to aid the driver, and avoid mishandling of the train or incorrect interpretation of signals. These systems range from in-cab warning systems to fully automatic control of trains

without engineers [69]. SEL Canada markets ATC equipment developed by Standad Electric Lorenz AG of West Germany. Their system utilizes wayside minicomputers and on-board microprocessors, with continuous two-way communication between trains and wayside by means of inductive cable, laid between the rails [75]. Train presence and position, are established as the on-train control unit counts transpositions of the inductive cable and reports its position to the wayside computers. Wayside equipment monitors the status of trains and controls them through use of commands to update stopping position, maximum allowable speed, and other operating parameters. The on-train control unit, can compute its own braking limits and supervise performance within the wayside-imposed limits, either through cab display (with provision for automatic brake application in the event of overspeed) or through full automatic train operation [75]. The system allows trains to stay relatively close to each other, thereby increasing railroad capacity.

Fully automatic train control has been used on ore hauling freight lines at Landor, Wyoming and on the Great Slave Lake Line operated by Canadian National. The latter is over 400 miles in length [76].

6.4 Automatic Car Identification (ACI)

Identification of rail car numbers is a basic function needed to check train consists at classification and interchange points throughout the system. Visual car number reading and verification has traditionally been the method used to accomplish this. Recently a number of automatic techniques for car identification has been tested. For instance a colored label system has been widely implemented but found to be inadequate in the railroad environment [77].

Labels, composed of colored reflective strips, were placed on the sides of rolling stock and locomotives. At key points along the line, photo-electric scanning devices read the labels as the vehicles passed by, and translated them into an electric signal [78]. The signal was fed into a centrally-located computer which then formed up-to-date records of the whereabouts of all vehicles in its domain. However, the labels were not maintained in clear condition and as a result reading accuracy suffered. Further, through the use of centralized computer systems, manual entering of car locations and car inventories was made faster, and hence the potential gain of ACI seemed diminished [79]. Currently ACI is being used by only a few railroads, but research and development is continuing.

Probably the most advanced ACI system under development is the SICARID system, made by Siemens. An antenna mounted between the rails transmits a signal to passive transponders mounted in the cars passing overhead. The cars, in turn, return

uniquely coded signals to an interrogator receiver which transfers the signal to a central computer to identify the progress of the train. This system shows a very high degree of dependability [71].

General Motor's Transportation Systems Center is developing an ACI system much like the traffic control system being tested on the British Columbia Railroad, except in reverse. Cars carry inert transponders, which are energized by active wayside interrogators [96]. The information transmitted by the transponders is received and decoded by the interrogator. The transponder carried by each car will contain an unique code. Hence, car identification will be realized in a similar manner to those systems already mentioned.

6.5 Future Trends

Future trends in CTC may be summarized as follows:

a) the role of the computer will be increased, particularly in communications and clerical work. This will permit the dispatcher to concentrate on train control;

b) the use of touch-point control will be increased. Instead of transmitting instructions via a keyboard, the dispatcher will do so by touching a point on a screen or display. This will further quicken dispatching operations;

c) increased capability in determining train speeds so as to make meets occur with a minimum of stand still time (i.e., with one train sitting on a siding) should increase railroad capacity, reduce braking and accelerating requirements, thus saving money on maintenance and fuel [75]; and

d) communications links with other computerized operations will be utilized to automatically obtain nearly all of the data required by a dispatcher to perform his duties. These links will eliminate the requirement for each user to re-enter required data by automatically passing it to the next user. Links with other CTC computers, yard computers, crew dispatching computers and the railroads' larger central control systems will permit it to control and monitor nearly all aspects of train operations.

ATC systems, particularly those designed to provide driver aid, should be developed further in the near future. Fully automated trains without drivers may be used in private operations or captive unit train service in sparsely populated

areas. In most operations an engineman will still be required due to union requirements, external factors such as frozen switchgear, safety requirements, or other unforseeable circumstances.

To keep track of North America's two million cars and locomotives, an improved ACI system will probably be implemented. An active component on the car or some form of electrical connection between cars and locomotive would be a major step towards improving freight car monitoring functions involving fault detection and train handling performance [72].

6.6 Summary

The introduction of computers and micro-processors has improved the efficiency of traffic control systems, particularly in the area of centralized traffic control. Larger rail areas may be dispatched from a central office, resulting in increased capacity of existing lines. Under automatic train control, accelerating and braking requirements may be met without excessive fuel loss or brake wear, hence lowering operating costs. Administrative work may be carried out more efficiently by the use of computerized information management systems. Automatic car identification, which had disappeared from service over the last five years is likely to reappear in a more advanced form.

Chapter 7

MARSHALLING YARDS

7.1 Introduction

Chapter 7 reviews the development of marshalling yards from the first hump yards built in 1880 to the present day computerized yards. The components and operation of a modern marshalling yard are explained including the receiving yard, hump lead, classification yard bowl, departure yard and support yard. The applications of computers and some foreign developments in hardware are discussed, followed by a brief outline of future trends.

7.2 History of Development

The marshalling yard is the area where rail cars or groups of cars are sorted and assembled into trains before being dispatched onto the main line. Railway yards are usually located at major transportation centres, but occasionally they are located in sparsely populated areas. The most efficient yards today are those which operate on the gravity-assisted, or "hump" system. A high capacity yard can process some 6 000 cars per day.

As early as the 1880's artificial mounds, or humps, were introduced, from which cars could gravitate to their correct sidings [78]. Before this, yards were flat, and a great deal of engine power was required to shunt the cars in and out of sidings. In a hump yard operation, a train is pushed up a slight grade, and individual cars are uncoupled at the crest of the hump, to roll freely down the other side. Through the use of track switches, the cars may be directed to a predetermined siding. Here coupling takes place automatically, when the car runs into those cars already on the siding (the first car over the hump couples with the locomotive).

Before the development of the car retarder, car speed during humping was controlled by men who rode on the cars and applied hand brakes. The breakthrough which provided impetus toward complete mechanization was that of the car retarder. Developed in the United States shortly after World War I, the system utilized a brake mounted at a fixed location on the rails instead of on the freight car. The retarder was controlled by one brakeman stationed alongside the track. Hence, fewer men were needed to control car speed. Although the car retarder improved the efficiency of yard operation, human judgement was

still required to adjust the speed of the approaching freight car through the correct amount of brake application. This frequently led to damage of the freight car ends due to rough shunts. The next major development in braking devices for shunting freight cars in the yard was the fully automated retarder control. This device, along with pushbutton control of track selection, was first used in the 1950's. In automatic operation an analog computer was used to select retarder car speeds based on predetermined car rolling performance [76].

Several types of retarders are now in use. Eddy current brakes use electrodynamic forces to slow a car down as it moves through the electrical field created by the brake. Plunger type brakes slow the cars down to a predetermined speed by forcing the wheels to pass over and compress a series of pneumatic plungers. The force exerted by the plungers varies directly with the speed at which the wheel strikes them. A third system used in some European yards uses a screw type retarder. As the car wheels pass along the length of the screw it forces the screw to turn. A retarding force is exerted by a hydraulic damper which resists rotation of the screw.

In the mid-sixties the first digital computer control systems were introduced. The early systems controlled the track switching operations and controlled the retarder forces to provide the correct exit speeds of cars. Following this development, computers were used to keep a running inventory of the number and type of cars shunted into each train. Automatic car scheduling systems, for example, have reduced freight car terminal times from 18 to 12 hours [79]. Within such a system, messages of car movements are forwarded to stations, yards, and terminals. This includes advance information of train makeup, car distribution, and special handling instructions which will speed-up the yard operation.

7.3 Modern Marshalling Yards

Advances in computer technology and process control for interfacing the computer with the hardware in the marshalling yard have led to development of automatic freight classification yards. The typical tasks of a marshalling yard control system include [80,94]:

a) safe, expedient, damage-free throughput of cars;

b) reduced terminal time for freight cars and locomotives;

c) improved use of resources (engines, yard crews, administrative personnel); and

d) up-to-date, accurate information and documentation of cargo manifests.

Although yard layouts vary, the following major components generally make up a modern yard:

a) the receiving yard, typically 10 tracks. It may include a track for cars which are not designed for hump operation;

b) the hump lead is generally equipped with a "weigh-in-motion" scale and a master retarder on the descending side;

c) the classification yard bowl, with up to 60 tracks is where the trains are built-up. It usually includes secondary retarders located on the tracks which feed from the main hump track to the classification tracks;

d) the departure yard contains up to 10 tracks. It is used for further train assembly and inspection;

e) the support yard is used for bowl track overflow and to contain local and industrial cars. It may include C/TOFC facilities;

f) the car shop is used for car repairs and cargo adjusting; and

g) the locomotive shop is used for servicing of engines.

Figure 7.1 illustrates the operation of an automated hump yard.

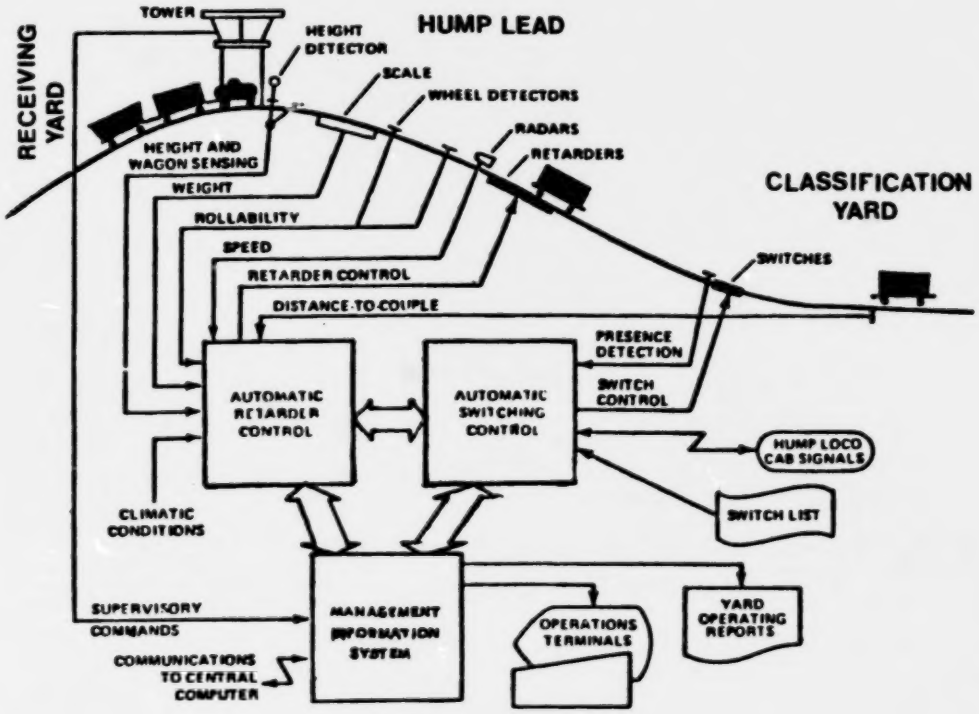
The car being humped passes over the crest and is uncoupled to roll free down the grade. The car passes over the electronic weigh scale and the car weight is input to the process computer. As the car proceeds, a wheel detector indicates that the car is approaching the retarder and speed direction doppler radar. The computer uses this information and the weigh scale value in setting the retarder to the braking force necessary to assure the proper exit speed. The car is then switched onto the proper bowl yard track. Additional detectors and retarders slow the car to a proper coupling speed of three to four mph as it strikes the preceding car in the train [81].

7.4 European and Japanese Developments

Some innovative designs have been developed for automated hump yard operation in Europe. In Basel, Switzerland the receiving yard track is on an incline and retarders are used to hold the approaching trains on the slope. No separate locomotive is needed to push the train over the hump. As the

Figure 7.1

AUTOMATED HUMP CLASSIFICATION YARD



Source: [82]

cars are released, they pass over a secondary retarder into the classification bowl. Here movement of the car is controlled by a "mule" as illustrated in Figure 7.2. The mules are tow cars which run between the rails of each classification track. A car may pass over the mule without interference, but when needed for propulsion or retarding, a set of rollers are extended upwards from the mule to engage against the perimeter of the freight car wheel flange. A cable driven by an electric motor under the track then controls the movement of both the mule and freight car [83].

A similar system, with a few modifications, is currently being marketed by the German firm of Hermann Vollert AG, Machinenfabric. In this system, a separate narrow gauge track is provided for the mules to run on, within the normal train track. The mules carry rollers which, when extended sideways, impinge on the flanges of the car wheels, driving it forward.

In Japan, at the Shiohama marshalling yard in Kawasaki City, a system similar to those in Europe is used but incorporates self-propelled mules to move the cars through the classification yard. The yard is basically a hump yard with primary and secondary retarders. The yard is located near the sea and is subject to strong winds which greatly affect car speed. The self-propelled mules run on separate narrow gauge tracks and are driven by linear induction motors which give accurate positive control of the freight car speed. Cars are picked up at one end of the yard and pulled along at 8 to 9 mph until they reach a predetermined distance from the waiting group of cars being assembled. The mule slows down and then releases the freight car at its proper coupling speed. The mule returns to the other end of the yard at a higher speed until it picks up another car and repeats the process [83].

The advantages of the Japanese system include:

a) the highest car control speed of any system so far developed. Hence, yard operations take less time;

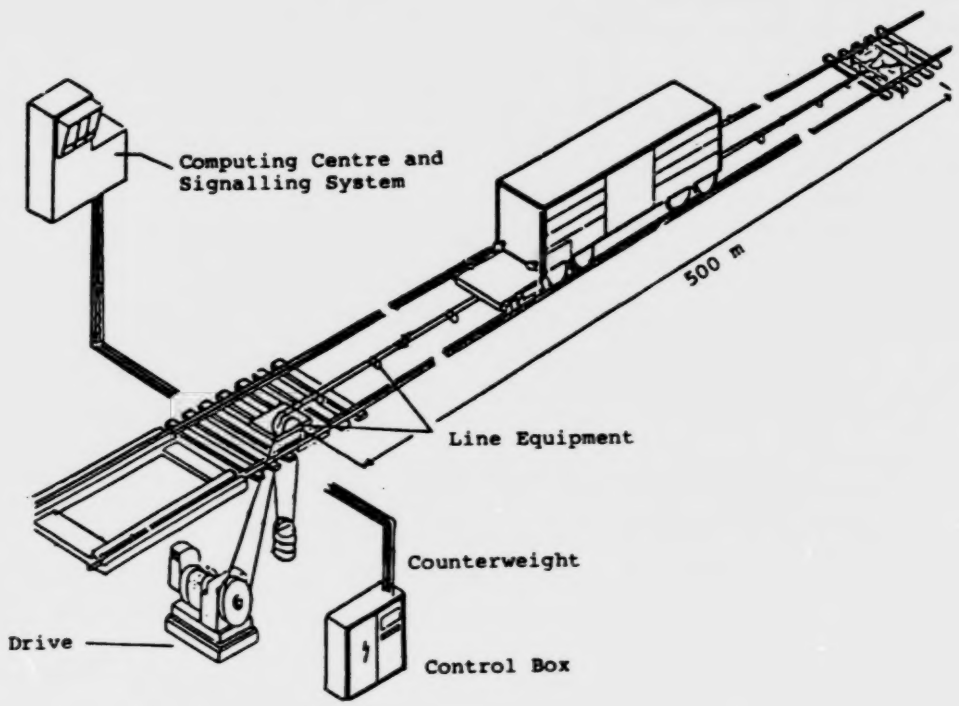
b) the availability of acceleration and deceleration, once a car has passed the secondary retarders. This minimizes the influence of disturbing factors such as high wind and unfavourable car rolling characteristics;

c) automatic operation programs incorporated within the speed control units. These lessen the burden on the central control system; and

d) comparatively light speed control devices. These can exert large driving and braking forces due to use of the linear induction motor.

Figure 7.2

ROPE-HAULED MULE SYSTEM



Source: [83]

7.5 Future Trends

The following trends are expected in marshalling yards in the near future:

a) the trend toward total integration of the car control process will continue. Emphasis will be on process control which interfaces the computer with the hardware in the marshalling yard;

b) coupling speed measurement devices will be refined. This will lead to dynamic self-calibrating control systems [81];

c) standard yard components (receiving yard, classification yard, etc.) will remain unchanged;

d) there will be more emphasis placed on improvement of older yards as opposed to construction of new ones;

e) with yard efficiency increasing, there may be an effort to reduce the number of yards in service and ensure that those in service are at key points; and

f) the labour content of marshalling yard operations will be reduced through automation. This will include such innovations as automatic brake line coupling, thereby eliminating this labour intensive activity. Radio controlled shunt locomotives may also be used.

7.6 Summary

Improvements in mechanical control systems, coupled with the advent of computer technology have increased the number of trains which may be handled in marshalling yards. Technologies such as the car retarder have reduced the number of operating personnel required, as well as providing opportunity for interface with computers. Benefits which have resulted from the use of computers include reduced terminal time (which leads to savings in fuel as well as other resources) and timely information for management and administrative purposes. Foreign countries have developed systems involving pulley or self-propelled mules which provide for greater car speed control during the coupling process in the classification yard.

Chapter 8

RAILWAY TRACKAGE AND MAINTENANCE OF WAY EQUIPMENT

8.1 Introduction

The history and future of track developments are presented in this chapter. Systems examined include: electrified track, rail developments, maintenance of way equipment, concrete ties, continuously supported track, and geotextiles for roadbeds. The expected future developments are discussed within the appropriate sections. The greatest area of technological development is in maintenance of way equipment. Canadian railroads are leaders in this field. They are now testing machines capable of performing six separate maintenance functions in one operation.

8.2 History

The greatest period of railway expansion terminated with the stock market collapse of 1929. In addition to the great depression following this collapse, a drought condition developed across the prairies further reducing railway expansion. However, isolated railway extensions took place via: a line to Port Churchill, mineral developments including the Québec North Shore and Labrador Line from Sept-Îles to Schefferville, and the northward extension of the Northern Alberta and the Pacific Great Eastern Railways.

From 1945 to 1978 first main line trackage dropped from 42 352 miles to 42 185 miles, a decrease of 0.4%. The abandonment of many branch lines on the prairies is presently being considered as grain can be trucked easily to elevators on mainline trackage.

If one includes second main track, third, and other main track, industrial track, yard and siding trackage, then the total railway plant is some 36% greater than that previously mentioned. A comparison of the miles of trackage 1945-1978 is given in Table 8.1. The breakdown of all trackage in Table 8.1 indicates that:

70.0% is first main line
3.0% is second main line (second line of double track)
0.1% is third line main line (third line of a triple track)
6.0% is industrial trackage
20.0% is yard and siding trackage.

Table 8.1

MILEAGE OF TRACK OPERATED IN CANADA 1945-1978

Year	All Track	First Main Line
1945	56 937	42 352
1946	57 005	42 335
1947	50 051	42 322
1948	57 005	42 248
1949	57 834	42 978
1950	57 997	42 978
1951	58 150	42 956
1952	58 921	42 953
1953	58 695	43 163
1954	58 760	43 132
1955	59 316	43 444
1956	59 830	44 769
1957	59 097	44 839
1958	59 319	45 164
1959	60 293	44 209
1960	59 193	44 029
1961	58 783	43 689
1962	58 759	42 654
1963	58 511	42 623
1964	58 243	43 355
1965	48 202	43 157
1966	58 100	43 003
1967	58 530	43 168
1968	58 658	43 168
1969	59 115	43 613
1970	59 628	43 983
1971	59 710	44 153
1972	60 037	44 024
1973	60 246	44 232
1974	60 247	44 266
1975	60 045	43 941
1976	59 850	43 789
1977	59 022	43 476
1978	58 462	42 185

8.3 Electrified Track

A small amount of electrified track exists in Canada. This is composed of a DC powered CN line running through the Mount Royal tunnel in Montréal, the B.C. electric railway, which is essentially for interurban passenger service, and about seven miles of automated ore-haul line in Sept-Îles, Québec. Electric railway activity in the past in Canada has either remained static or diminished as indicated by the number of electric locomotives in service (see Figure 2.1). Currently, there are plans to electrify a section of ore-haul line in Northern Québec on the Cartierville Railway. This may serve as a pilot project for further electrification in Canada.

The only operating electrified freight line in North America using commercial 50 KV, 60 Hz power is the Black Mesa and Lake Powell Railroad in Arizona. This rail line, 78 miles in length, uses a single automated train hauling coal. It makes up to three round trips per day. There are however, electrified lines in the United States used primarily for passenger transport, i.e., in the New Haven to Baltimore Corridor.

8.4 Rails

In the early 1800's wrought iron rails were typically used. They were often laid on bare ground or sometimes supported by stone blocks. In the late 1870's, steel rails with greater strength and wearing qualities began to replace iron in rails. Typical main line rail size has increased steadily, from four inch depth and 32 lbs. per yard to 6½ inch depth and 132 lbs. per yard. Currently maximum rail size is in the eight inch depth and 150 lbs. per yard range [78]. The majority of new rail laid in Canada is the 132 lbs. per yard class.

Presently, most new rail is a heat treated carbon steel. In the future carbon steel will likely be replaced by alloy steels. Alloys containing chromium, manganese, columbium or vanadium are claimed to have improved rail strength and wearing qualities over carbon steel rails [84]. The move to heavier, stronger rails reflects the higher average axle loads and the heavier traffic on most lines. As traffic increases the time available for maintenance crews to service the line is reduced. Use of premium quality rails in conjunction with good ballast and ties increases rail changeout intervals from some three years to six or seven years on heavily travelled lines. In Canada, it is now standard practice to lay 1 400 ft. continuous welded rail with concrete ties for new installations particularly where heavy grades and high traffic volumes are prevalent [72]. To minimize the thermal stresses produced in a continuous rail, heating or cooling is used during the track laying operation. For example, before being permanently fixed in the rail structure, the rail is heated or cooled to the

medium temperatures of the region in which the track is laid [78]. This reduces the maximum thermal stresses due to varying ambient temperatures.

8.5 Maintenance of Way Equipment

As traffic increases over a line, the time available for track maintenance on a single line between trains decreases. Maintenance of way (M/W) equipment which runs on the track must be driven to the site, maintenance operations carried out and be returned to the siding during the track time "window" or period of time between train passes. New developments in M/W equipment are aimed at reducing labour requirements while speeding up and combining several maintenance functions into one operation. The state-of-the-art track machine is the Canron P811 for rail and concrete tie replacement, used by CN and CP. It is a conveyor type machine which in one series of operations lifts the old track, removes the rail and ties, cleans the ballast, lays and spaces new concrete ties, lays new 1 400 ft. continuous welded rail and fastens the rail. The machine has a design speed of 2 000 ft. per hour. Estimates of cost savings on rail replacement run as high as $3 million per year [84]. Combining six operations into one machine eliminates segmented operations, the slow speed of small machines, and the large work forces needed for rail replacement.

The increasing frequency of heavy trains and the rising cost of ballast (crushed stone, which transmits forces from the ties to the subgrade) have increased the importance of ballast maintenance machines. An under-cutting ballast cleaning machine, on lease from Kershaw Manufacturing of Alabama, has been in use by CP Rail for the past eight years [85]. Ballast from alongside, underneath and between the tracks is loaded onto a conveyor, and carried to a cleaner, which separates out the waste material. The cleaned ballast is returned to the track and the waste is discarded (shown being deposited at trackside in Figure 8.1). Workmen replace worn-out ties during the operation. Production rate is in the range of 1 500 - 1 600 ft. per day.

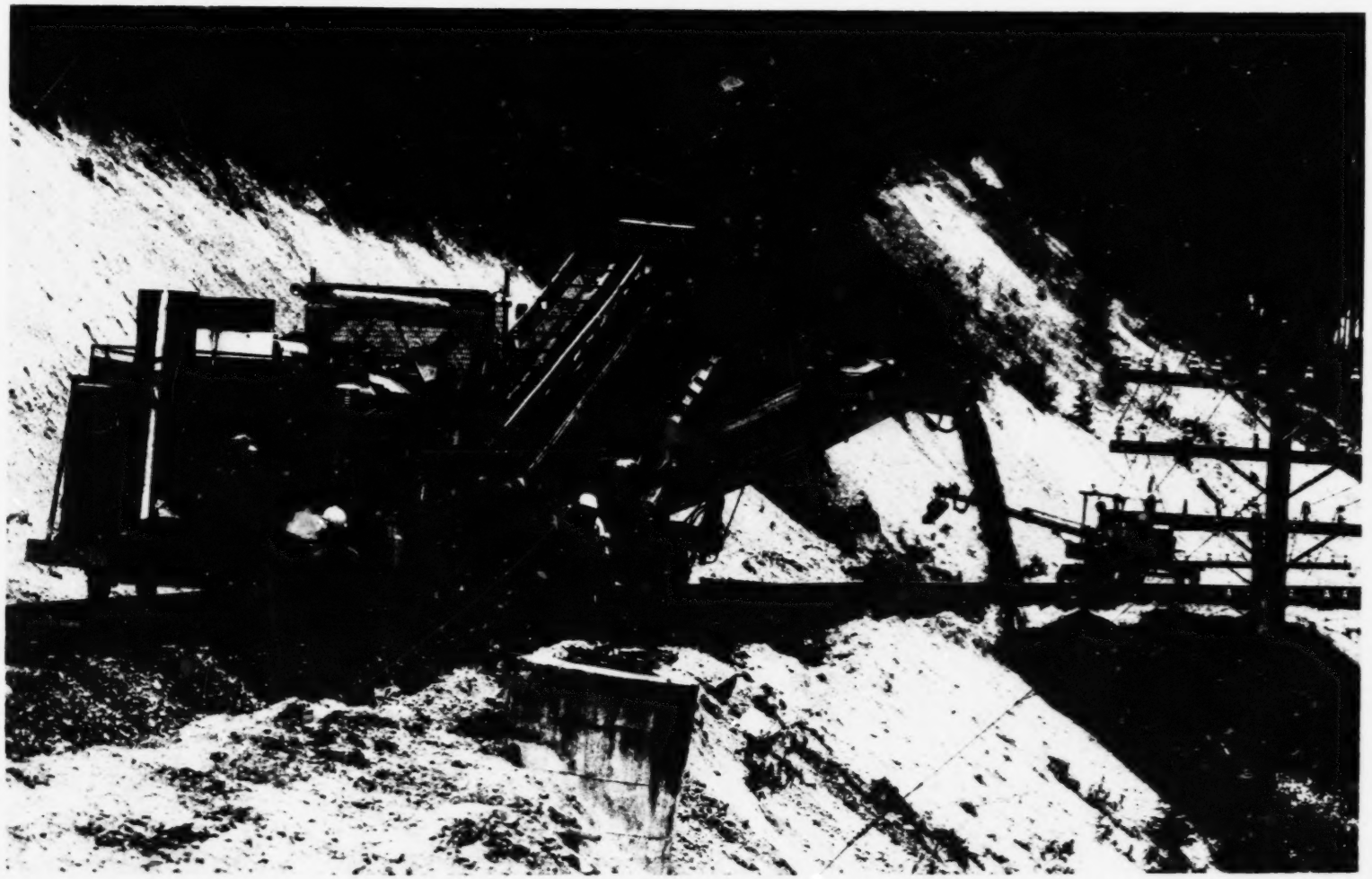
After ballast is cleaned and new ballast added from a work train, it must be compacted or "tamped" to give it additional stability. Technological developments are anticipated in the near future which will increase the design speed of automatic tampers. In the past this was a manual operation. Current automatic tampers operate at about 2 400 ft. per hour. A prototype model produced by Canron and being tested by CP is hoped to achieve a rate of 3 mph.

In the near future developments in M/W equipment will also include:

a) faster more reliable spiking machines;

Figure 8.1

UNDERCUTTING/BALLAST CLEANING MACHINE



Source: [85]

b) faster improved mobile welding equipment for continuous welded rail with combined highway/rail running gear;

c) greater use of rail grinders to resurface rails thereby reducing frequent changes on heavily trafficked curves; and

d) the use of spot maintenance equipment that doesn't occupy the track.

Future track maintenance equipment will likely evolve into two categories. Large multi-function units similar to the Canron P811 will carry out the major rebuilding of track sections. Smaller, single function portable equipment with multimodal rail/highway capability will be used to carry out spot repairs between major rebuilds. These smaller units will be able to clear the track rapidly at highway level crossings without interfering with train schedules.

In general, maintenance equipment improvements will be aimed at increasing the speed of operation, reducing labour requirements, simplifying maintenance equipment and improving reliability.

Other track machines are also used for detection and measurement of faults in the rail. Track geometry cars have been in use since the 1960's. These are used to measure such parameters as track radius of curvature, superelevation and any irregularities in horizontal and vertical alignment. Measurements of this nature are useful in determining quantitatively if the track structure is maintaining geometric integrity, which of course is crucial to safe train operation.

Railhead wear-machines have recently been introduced. They are pulled over the track at speeds of 10-20 mph. One such machine operated by Southern Railway in the United States provides a continuous record of head contour [86]. If a rail is found to contain unacceptable corrugations, then grinding machines may be used to remove the irregularities rather than changing out the rail [84].

8.6 Concrete Crossties

Wooden crossties have been the standard in track laying since they were introduced in the early 1800's in England by George Stephenson, (considered to be the inventor of the modern railway) [78]. In the late 1950's, experimentation began with pre-stressed concrete crossties. The first North American installation occurred about 20 years ago on the Atlantic Coast line in Florida [87]. Opinions on their performance have been varied and widespread implementation has yet to occur. CN is using them in its mountain region (which has severe weather and very sharp curves) on the 125 mile Ashcroft Subdivision.

Due to the following advantages, an increased use of concrete ties is expected:

a) they have a 50 year versus a 25 to 30 year life expectancy for wooden ties;

b) maintenance costs are reduced by 30%;

c) improved fuel efficiency; and

d) increasing costs of wooden ties [88].

A recent study, which took place at the United States Department of Transport's test facility near Pueblo, Colorado [89], identified the following areas as requiring additional research in the development of concrete ties:

a) criteria for the specification of ballast quality, ballast consolidation, and/or speed restrictions to assure running safety after ballast maintenance;

b) the effects of maintenance procedures on ballast compaction;

c) the prevention of damage to ties and fasteners during normal track maintenance operations; and

d) improvements to selected rail fasteners to increase fatigue life and to reduce rail creep and tie movements [89].

8.7 Continuously Supported Track

Continuously Supported Track (CST) consists of a continuously reinforced concrete foundation to which the rails are directly fastened. The concrete foundation takes the place of conventional ballast and crossties. Test sections of this type of track structure have been built in England, Italy, Spain and Japan [90].

The advantages expected through the use of CST may be summarized as follows:

a) the cross section is simple and small in height. This should reduce construction costs, especially in tunnels;

b) the use of concrete should decrease maintenance costs on curves, in tunnels or other areas where routine maintenance is difficult; and

c) the system should reduce rail displacement on curves. Hence speed limits could be raised.

A Japanese study found that track geometry accuracy suffered due to a lack of finishing accuracy in placing the rails on the concrete [90]. CST may see limited North American application if foreign testing proves successful.

8.8 Geotextiles

Geotextiles are polyester or polypropylene fibre mats which are rolled out over the natural earth subgrade or sub-ballast of the roadbed. The purpose of the geotextiles is to reduce weakening of the roadbed due to water intrusion. Roadbed failures, which can cause derailments, are almost invariably caused by high water concentrations. To counteract this, the mats act as wicks which halt the upward movement of water and draw it out laterally to the sides of the roadbed. The fibres also prohibit the migration of soil particles into the ballast through the pumping action of passing trains. Cleaning a ballast section fouled and weakened by the intrusion of smaller soil particles is an expensive maintenance operation. The pumping action of heavy freight trains also has the effect of drawing subsurface water up through the subgrade into the ballast [91]. Fibre mats stop the process and the pumping may actually help to squeeze the water out laterally. Geotextiles also contribute to stability by distributing loads over a wider area of subgrade.

First used in North American railroads in the mid-1970's, geotextiles provide a relatively inexpensive solution to many drainage problems over short distances of roadbed. Their use is expected to increase in the future.

8.9 Summary

Since 1945 the mileage of first main-line track has changed little. From 42 352 miles in 1945, first main line track peaked at 43 941 miles in 1975 and has shown a slight decline since.

Electrified track installations occur in: some 300 miles of passenger rail in the northeast corridor between New Haven and Baltimore, a 78 mile private coal line in Arizona, and a 7 mile automated ore-haul line in Sept-Îles, Québec. There are plans to electrify a section of ore-haul track in Northern Québec and monitor its operation as a pilot electrification project.

Materials research is developing new steel alloys with better wearing and strength characteristics to replace the carbon steel in rails. Most new rail now is 132 lbs./yd. continuous welded rail, installed in 1 400 ft. lengths. Use of this heavy rail reduces the frequency of rail changeouts under conditions of high traffic and heavy axle loads.

Track maintenance equipment will likely evolve into two types. Large rail changeout machines capable of removing track and re-laying new in one operation, will be used increasingly for major track rebuilding projects. Smaller highway/rail portable maintenance units, each performing only one function, will be used to carry out periodic spot maintenance between major overhauls. As the time available between train passes becomes shorter, the emphasis on maintenance equipment design will be on increased speed of operation, reliability, simplicity and automation.

The value of concrete crossties has yet to be proven. They cost twice as much as wooden ties having a life of 30 years. The expected life of concrete ties is 50 years. They are also reported to reduce maintenance costs by 30% and increase locomotive fuel efficiency by maintaining better alignment. On Canadian roads, concrete ties are now used regularly to replace wooden ties where steep grades and heavy traffic prevail.

Continuously supported track, which uses a concrete bed to support the rails, is being tested in foreign countries. In North America it may offer a means of reducing costs in sections where tight curves or tunnels increase maintenance costs or make maintenance difficult.

Geotextiles are now being used to improve the stability of roadbeds in areas where water penetration is a problem. The mats act as wicks which draw the water off laterally to the sides of the roadbed.

Chapter 9

PRODUCTIVITY TRENDS

9.1 Introduction

In Chapters 2 to 8, the technological changes since 1945 have been examined. This chapter shows the changes in productivity over the same time period. Traffic has increased by a factor of 2.5 while the mileage of track, number of locomotives and number of freight cars has remained relatively unchanged. This reflects underutilization of low volume branch lines and sidings in the past coupled with technological advances and institutional changes over the selected time period. In this chapter the impact of major technological changes is highlighted.

The trend lines generally represent two distinct periods. From 1945 to 1962, the railroads were converting from steam power to diesel power. Between 1963 to 1978, the conversion was completed and further productivity became limited by changes in locomotive power and train size. Throughout this chapter the "ton-mile" unit is used as the approximate measure of physical productivity. The productivity trends presented are all for Canadian railways.

9.2 Review of Trends

An example of an institutional change which contributed to the upward trend in the productivity of labour began in 1957 (see Figure 9.1). A succession of employees hired during the peak of railroad activity prior to the depression were beginning to retire around this time after some 30 or 35 years of service. Upon retiring many of these employees were not replaced.

The upward trend is also a result of technological change. With the conversion from steam to diesel power, a large number of employees in water and coal servicing and locomotive maintenance were no longer needed. Their numbers were reduced through attrition rather than by layoffs.

The advances in technology and increasing labour costs have since contributed to the steady decline in the number of employees. Computer technology has increased the efficiency of traffic control systems and marshalling yards, which have undergone reductions in operating personnel. Mechanization of loading/unloading systems has contributed to a decrease in

Figure 9.1

TON-MILES PER EMPLOYEE
1945-1978

Sources: [3, 4]

employee numbers. Measured in "ton-miles/employee" the productivity of labour has increased by a factor of four since the 1950's.

Since 1945, increases in fuel efficiency have been almost entirely the result of technological change. Only recently have train operating policies and educational programs started to affect fuel consumption.

In Figure 9.2, we see a sudden increase in the number of ton-miles generated per British Thermal Unit of fuel consumed. This increase corresponds to the demise of steam power as diesel locomotives with six times the thermal efficiency of steam units began to take over.

As diesel engines were further refined over the years, more modest increases in fuel efficiency were realized. Turbo-charging, although it dramatically increased the power output possible from a single unit, did not result in radically improved fuel economy. With rising fuel costs constituting an ever larger share of operating expenses, the demand for more fuel efficient locomotives is again starting to turn the energy productivity curve upward.

The development of higher capacity freight cars contributes to the productivity of several factors. Figure 9.3 shows that while the miles per loaded freight car has increased 23% since 1945 the number of ton-miles per freight car has increased 94%. The increased productivity is a result of greater average payloads and higher annual utilization. More and more freight cars are being designed for the maximum 60 000 lb. axle loads while simultaneously decreasing the tare weight of the freight car. The result is a higher average capacity.

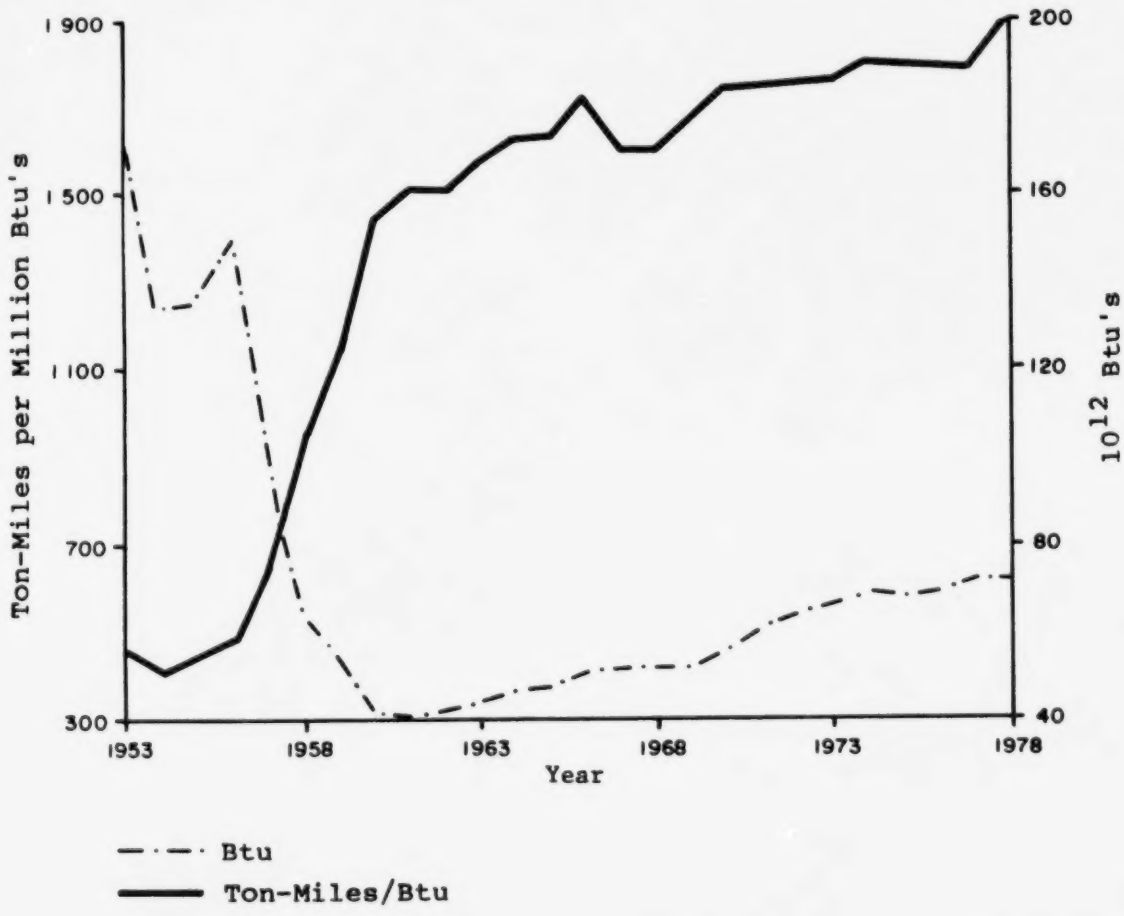
In addition to higher capacities there is also a trend towards increasing the average payload to capacity ratio. The growing number of resource hauling freight cars, loaded at or near their maximum capacity, is increasing the average car load factor. Higher capacities combined with higher load factors account for the increased average load per car shown in Figure 9.4.

As the number of older lower capacity freight cars declines, future increases in ton-miles per car will be a result of higher utilization of freight cars with shorter terminal times and less maintenance downtime. Higher average loads per car and greater utilization in turn increase the productivity of labour, capital and materials.

These trends have been in response to two influences. First, the high cost of capital for purchasing additional freight cars to provide a given level of capacity encourages development of higher capacity cars. Secondly, the rising cost of fuel has encouraged the trade-off of tare weight for payload.

Figure 9.2

TON-MILES PER MILLION BTU'S 1953-1978

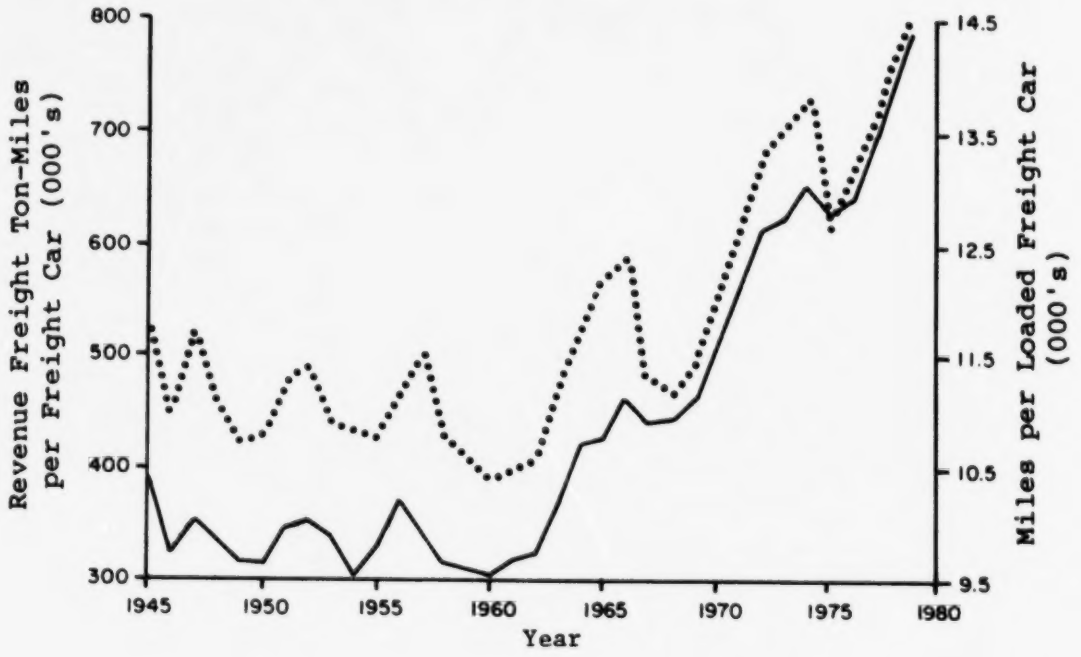


Sources: [3, 4, 51]

Diesel - 20 000 Btu/lb. (99 000 Btu/gl.)
Coal - 13 500 Btu/lb. (27×10^6 Btu/Ton)

Figure 9.3

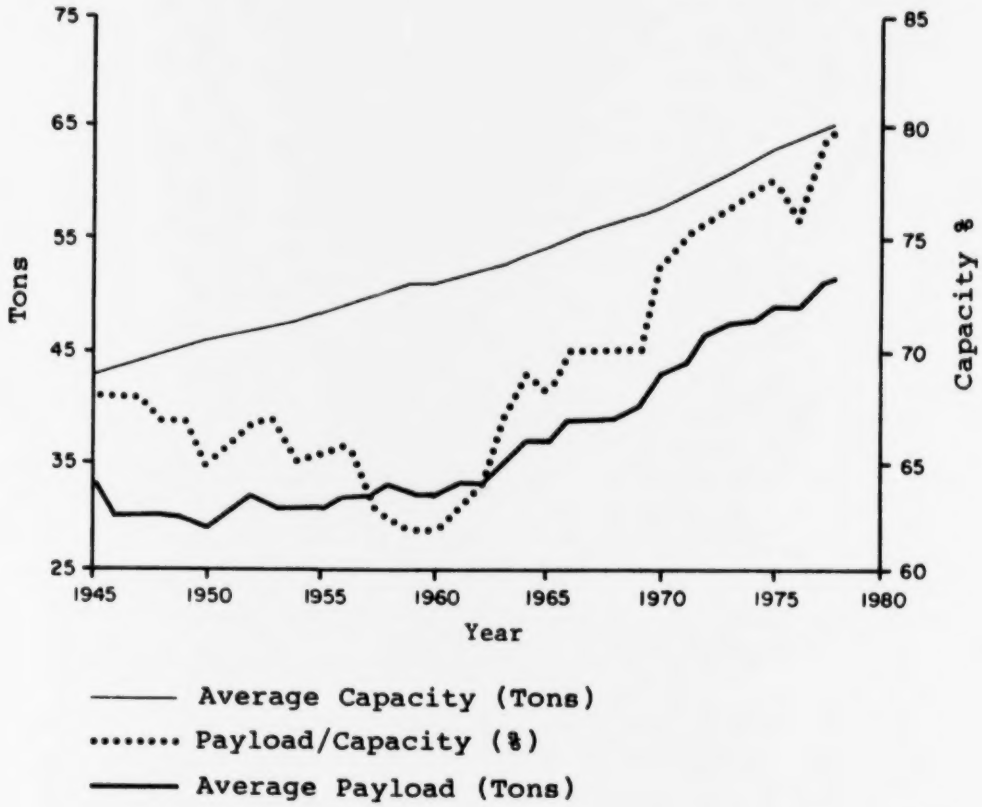
TON-MILES PER FREIGHT CAR
1945-1978



Sources: [3, 4, 51]

Figure 9.4

AVERAGE FREIGHT CAR CAPACITY AND LOAD
1945-1978



Sources: [3, 4, 5, 51]

The trend of increasing average loads will eventually peak out and possibly reverse itself. Present car designs have now reached maximum axle loadings and only modest payload increases can be expected through further tare weight reductions. Railroads are now pursuing more low density freight made profitable by high volume box cars and C/TOFC carriers. This will tend to reduce the average payload weight. Average freight car capacity could be expected to reach a plateau of 75 to 80 tons over the next ten years with a fleet mix of high weight and high volume capacity cars.

The productivity of locomotives in particular has increased under the influence of rising fuel and capital costs. Tractive effort improvements tend to reduce the number of locomotives required to overcome a ruling grade while maintenance and servicing improvements increase locomotive availability. Developments in all of these areas are aimed at reducing the locomotive fleet size required to deliver a fixed output. Figure 9.5, shows the change in the average number of ton-miles per locomotive over time.

The first major technological breakthrough was the conversion from steam to diesel power between 1948 and 1962. Following dieselization, the advent of turbo-charging nearly doubled the amount of work which could be performed by a single locomotive. As power outputs level off, further productivity gains are being realized through higher locomotive availability and improved traction characteristics. Productivity gains of course are also related to improvements in freight car design. Higher freight car capacities and lower tare weights produce greater amounts of revenue ton-miles for each gross ton of train weight.

The number of ton-miles per mile of track operated is a measure of the degree to which the existing system is being utilized. This is shown in Figure 9.6.

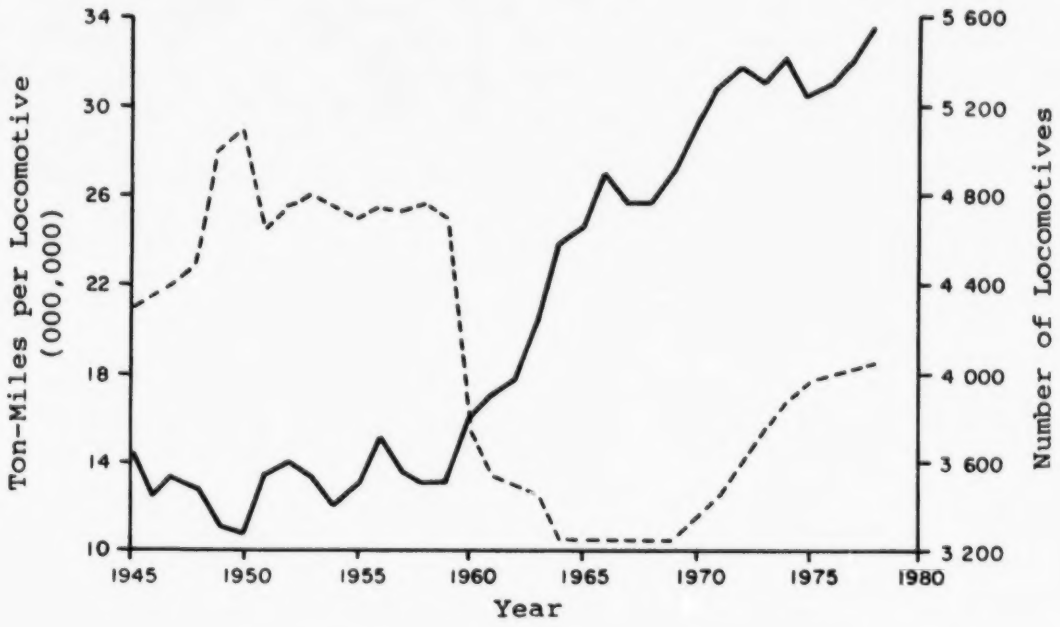
In 1962 the ton-miles per mile of track operated began a steady rise as a result of increasing demand without any significant increase in track mileage. After 1975, track mileage started to decline while demand increased and a rapid increase in ton-miles per mile of track resulted. This reflects a consolidation of traffic on mainlines where centralized traffic control systems can increase capacity of main lines without resorting to double tracking.

9.3 Summary

Productivity trends show the impact of technology and organization as the ratio of output in ton-miles to various inputs of labour, capital, and materials. Since 1945, labour productivity has increased from 300 to over 1 100 ton-miles per employee as a result of dieselization and the retiring of

Figure 9.5

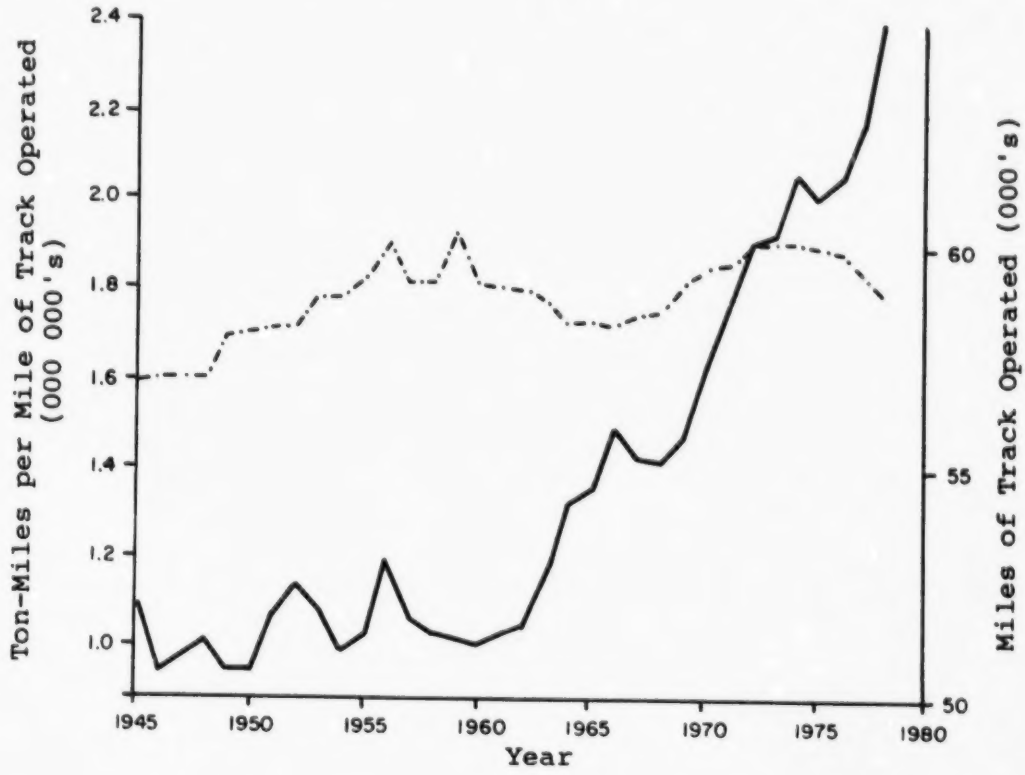
TON-MILES PER LOCOMOTIVE
1945-1978



Sources: [3, 4, 5]

Figure 9.6

TON-MILES PER MILE OF TRACK OPERATED
1945-1978



Sources: [3, 4, 5, 51]

employees hired during the peak of rail activity prior to the depression. Energy productivity has risen from 376 ton-miles per million Btu's in 1953 to 1 900 ton-miles per million Btu's in 1978. The major factor responsible for the improvement was the conversion from steam to diesel units. They are six times as efficient as the steam locomotives. Energy productivity is again starting to rise as technology improvements emphasize energy efficiency. Increased freight car capacities, higher load factors and improved annual utilization have increased the ton-mile output per freight car from less than 400 000 ton-miles per car in 1945 to approximately 750 000 ton-miles per car in 1978. Increased capacities reflect modern car design with a high structural efficiency, lower tare weight and maximum axle load. The gross weight of individual cars is not likely to increase over 265 000 lbs. unless there is a move from four-axle to six-axle freight cars. Higher utilization which also contributes to productivity is the result of reduced maintenance downtime, faster loading and unloading operations and reduced terminal times in automated freight yards.

Locomotive productivity since 1945 has increased from 14 million to 34 million ton-miles per locomotive-year. The technological advances which accounted for the increase were dieselization, which greatly increased locomotive availability, and turbo-charging which increased the power rating of individual locomotive units. More recently, locomotive productivity has further increased as a result of modest power increases, tractive effort improvements, higher availability, and the increased payload to gross weight characteristics of modern freight cars.

Ton-miles per mile of track has climbed steadily since 1962 from one million to nearly three million ton-miles per mile per year in 1978. Consolidation of traffic on mainlines under centralized control and abandonment of low volume branch lines has contributed to this trend.

Chapter 10

FUTURE ENVIRONMENT AND ITS TECHNOLOGICAL IMPACTS

10.1 Railway Development Scenarios

Long term technological change is guided by the external influences of the environment within which railroads must operate. As the course of events creating future environments cannot be predicted with any certainty, a "most likely" scenario is created. The directions in which technologies will evolve under this scenario to the year 2000 and beyond are speculated upon.

As with any form of forecasting, the only thing certain about it, is that it will not come true in all of its facits. The reasons are legion. It is sufficient to state that if the combination of current economic, financial, technological and political forces at work in Canada and the world grow as current developments indicate, then the future to the year 2000 will somewhat resemble that described in this chapter.

By necessity, this future look must be mostly subjective and general. A serious, in-depth examination of the next 20 years is outside the scope of this report.

The external factors which will influence the direction of rail technological development are identified in the following section.

10.2 Factors Affecting the Future Railroad Environment

Technologies are implemented and optimized both in response to the internal needs of the railroads and as a result of external factors over which they have no control. The external factors determine the environment within which railroads must operate. The principal factors making up this environment include:

a) energy;

b) capital;

c) labour;

d) demand;

e) government policy; and

f) regulations.

There are many additional factors that could be considered. However, the above are presented as trend indicators for each of the major groups of factors affecting developments.

Understanding the future relationships between these factors and railway operations will help identify the direction of future technological developments in the railroad systems.

The manner in which each of these six environmental factors affect the direction of technological development is described hereunder. In a subsequent section, a "most likely" environment is postulated and the resultant effects on technology are hypothesized.

Energy

Of all the external factors influencing technological developments, the price and availability of different energy sources will have the strongest single effect. In the short term, changes in energy prices and types available have brought about many fuel efficient technologies for immediate implementation. In the longer term, the uncertainty of diesel fuel supplies has stimulated the current search for alternate fuels and advanced propulsion systems for the future.

Within the spectrum of technologies available, the railroads will optimize their operations to reduce fuel consumption. Outside of the rail operation, energy issues may cause the entire pattern of transportation demand to shift.

Capital

The availability of capital is the most important factor controlling the implementation and timing of new technology. There is an abundance of new technology now available and railroads have an increasingly receptive attitude towards adopting it. In the capital intensive railroad industry, however, the resources available for implementation are limited.

The level of innovative research and development is also closely tied to the availability of capital. Research is often the first area to feel the shortage when scarce capital resources are allocated to operations.

Labour

Increasing labour costs exert pressure on railroads to automate labour intensive activities and to improve labour productivity through technological innovation.

Demand

The level and type of demand influences the development and type of technology required to provide a given capacity.

Government Policy

Policy decisions in many areas affect demand and technological development. Domestic policy on resource development and consumption influences the movement of resource traffic within the country. Political decisions influence issues such as electrification and double tracking. Without these external factors, decisions on such matters would be based on economic criteria as perceived by the railways.

The current domestic policy is to shift demand away from oil to gas, electricity, renewable energy, and coal [92]. This policy along with economic pressures has stimulated research into alternate fuels.

Foreign government trade policies will influence the level and pattern of import/export traffic to east and west coast ports. Energy policies will influence the energy choices and hence technologies to be pursued in the future. On the other hand a lack of policy will also delay the development of individual energy sources and technologies.

Regulations

The cost of complying with safety, environmental and operational regulations will divert some of the resoures available for technological development. In other cases regulations subsidizing the shipper who uses rail transport will stimulate traffic growth and hence technological development.

10.3 Most Likely Scenario

10.3.1 Description

a) In the most likely scenario, oil prices will continue to rise to the world price by 1990. As the price increases, more oil sources will become available thereby extending the time oil will be available. In the long term, oil will remain a preferred fuel until its price reaches the cost of alternate fuels. Coal is one example of a fuel that is priced at about 50% of oil but when its other costs are added to its price it is still more expensive. Hydrogen is an example of an expensive fuel that may eventually replace oil.

b) Capital will probably continue to be in short supply.

c) Railways will maintain or increase their share of high valued traffic as world wide movement of containerized cargo increases and as the cost of long haul domestic trucking increases. It is postulated that 25% of central Canada's coal requirements will be supplied from western Canada. Resource traffic for export will increase by 60% by the year 2000. Current growth rates of 15% per annum for intermodal and 5% per annum for carload traffic will continue.

d) A policy decision to electrify main lines will be made by the year 2000.

e) Double tracking will be an economic decision to be made by the railroads.

f) Foreign trade will increase but its growth will be constrained by competition in other markets, i.e., coal from Australia to Japan.

10.3.2 Technological Change

With increasing oil prices, the railways will shift to increasing use of off-specification and diesel hybrid fuels which may be used with a minimum of modification to existing engines. With mounting economic and political pressures to further reduce diesel fuel consumption in the 1990's, railroads faced with the choice of either purchasing radically new engines using substitute fuels or electrification will likely opt for the latter. Electrification technology for high density lines has already been well developed and proven successful in other parts of the world. Pilot electrification projects will likely be followed by a full scale implementation program for main lines starting around 1995.

Alternate energy and dual-mode propulsion systems will have an application on lower density lines which are not electrified. The trend however will be to reduce the number of low density lines for energy conservation and for economic reasons. These routes will be served by road instead.

In the short term locomotive fuel economy improvements of 25% (expressed in ton-miles per gallon) should be possible by 1990. This will entail evolutionary development of current designs, better control of train performance and operation, increased pay load capacity, better maintenance of motive power equipment and education of railroad personnel through the use of such devices as the locomotive simulator.

With capital in short supply, technological development will continue as an evolution of current designs. Radically new designs will undergo a long development period to ensure their

success upon introduction to the market. Capital will most likely be made available in the 1990's to electrify sections of main line.

Even after proven feasible, new technologies will be slow to be implemented due to the lack of capital. Railroads will concentrate on developing in those areas which produce the highest internal rates of return in the shortest period of time.

In the "most likely" scenario, lower wage increase demands and expanded personnel training programs would reduce the dependence on technology to improve labour productivity. Large capital expenditures such as are required to increase train length would not be economically justified. Optimum train performance would be controlled by engineers trained on simulators which duplicate conditions on a given route without the aid of sophisticated automatic train control systems.

Labour, in the most likely scenario, will receive better training through technologies such as the train simulator. More experienced workers when provided with technology advances will improve labour productivity. The level of wage demands will affect the speed with which labour saving technologies are introduced. They will not moderate to the extent the railroads would forego the implementation of most labour saving technologies.

Railroads will place more emphasis on level of service to increase their volume of C/TOFC traffic. This will result in reduced terminal time and improve on time performance. Automation in the freight classification yard and more specialized container handling equipment will contribute to this end.

Serving the wider resource traffic base will mean more and possibly larger unit trains in operation. Heavily loaded trains in turn will require upgrading of track structures and increased maintenance operations. The continuous welded rail and concrete ties now being placed in mountain regions may be installed throughout the whole mainline system where such heavy traffic is encountered.

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APPENDICES

Appendix A

GLOSSARY OF TERMS

Adhesion - refers to frictional force developed between contacting surfaces such as between a locomotive wheel and the rail.

Articulation - the sharing of one wheel truck assembly by adjacent ends of two vehicles.

ATC (Automatic Train Control) - term covering various systems designed to assist the driver and provide against mishandling or the misinterpretation of signals. Range from simple cab warning systems to fully automatic control.

Commutator - electronic device used to regulate direction of electric current.

Hydrogen Hybrids - iron compounds of metal can bind hydrogen to its molecules permitting hydrogen to be safely stored at modest pressures. By heating the hybrid, gaseous hydrogen is released for use as a fuel.

Naturally Aspirated Diesels - diesel engines which are not turbo-charged but receive their air supply at the ambient atmospheric pressure.

Rankine Cycle Engine - a heat engine such as a turbine or reciprocating steam engine powered by hot gases usually with the gases heated by an external combustion source.

Stirling Cycle - a constant volume heat engine powered by the rapid heating and expanding of gases inside a working cylinder. It generally uses internal combustion.

Tractive Effort - force available for pulling. The maximum tractive effort which a locomotive can generate is the product of locomotive weight and the coefficient of adhesion between the wheel and rail.

Transponder - electronic device (either wayside or on-board) which transmits information in response to a passing energizing signal.

Truck - independent short wheel base frame with four or six wheels capable of pivoting about the centre at which it is attached to the underframe of long vehicles.

Turbocharger - mechanical blower, powered by momentum of exhaust gas, which forces air into the engine under pressure.

Appendix B

Table B-1

PRODUCTIVITY TRENDS

Year	Ton-mile/employee (000's)	Employees (000's)	Ton-mile/ million Btu
1945	350	177	
6	310	176	
7	330	180	
8	310	186	
9	290	189	
1950	290	188	
1	310	201	
2	320	212	
3	310	209	376
4	290	194	416
5	320	192	442
6	360	202	480
7	320	199	640
8	340	181	948
9	350	1761	148
1960	370	164	1 463
1	390	1561	525
2	400	1541	512
3	470	1481	568
4	520	1491	660
5	540	1471	667
6	610	1451	725
7	590	1431	631
8	650	1301	631
9	680	1291	692
1970	780	126	1 750
1	860	124	1 754
2	940	122	1 769
3	990	118	1 773
4	1 020	122	1 812
5	1 020	119	1 806
6	1 090	114	1 797
7	1 150	112	1 792
8	1 220	112	1 903
Text Figure	9.1	9.1	9.2

PRODUCTIVITY TRENDS (cont'd)

Year		Revenue Freight Ton-miles/freight car (000's)	Miles/Loaded Freight Car (000's)	Ave. Freight Car Capacity (Tons)
1945		388	11.8	
6		329	11.0	
7		355	11.7	
8		337	11.1	45
9		318	10.7	
1950		314	10.8	
1		350	11.3	
2		362	11.4	
3	170	342	10.9	
4	137	302	9.8	47
5	138	330	10.8	
6	150	375	13.0	
7	100		11.5	
8	63	315	10.8	
9	54	312	10.6	50.9
1960	41	305	10.4	51
1	40	319	10.5	51.2
2	41	326	10.6	51.5
3	44	369	11.2	52
4	47	422	12.3	52.4
5	48	426	12.2	53.5
6	51	466	12.4	54
7	51.5	444	11.3	54.9
8	51.5	447	11.2	55.8
9	52	468	11.4	56
1970	56	519	12.1	56.5
1	61	572	12.7	58
2	65	615	13.3	59
3	66	626		60
4	69	654	13.8	60.8
				62

PRODUCTIVITY TRENDS (cont'd)

Year		Revenue Freight Ton-miles/freight car (000's)	Miles/Loaded Freight Car (000's)	Ave. Freight Car Capacity (Tons)
1975	67	627	12.7	63
6	69	642	13.2	64
7	72	690	13.6	64.5
8	72	753	14.5	65
Test Figure	9.2	9.3	9.3	9.4

PRODUCTIVITY TRENDS (cont'd)

Year	Ave. Payload Tons	Ton-mile/ Locomotive (000 000)	Locomotives (No.)	Ton-mile/ Mile of Track Operated (000 000's)	Miles of Track Operated (000's)
1945	32.8	14.4	4300	1.09	56.9
6	30.0	12.4	4350	.95	57.0
7	30.4	13.4	4400	1.18	50.0
8	30.3	12.9	4500	1.02	57.0
9	29.8	11.0	5000	.95	57.8
1950	29.1	10.8	5100	.95	58.0
1	30.8	13.5	4650	1.08	58.2
2	31.9	14.1	4750	1.15	58.3
3	31.4	13.3	4800	1.09	58.7
4	30.7	12.0	4750	.97	58.8
5	30.6	13.0	4700	1.03	59.3
6	32.1	15.2	4735	1.20	59.8
7	31.7	13.5	4725	1.08	59.1
8	32.5	13.1	4750	1.04	59.3
9	31.7	13.2	4700	1.03	60.3
1960	31.7	16.0	3750	1.01	59.2
1	32.7	17.2	3550	1.04	58.8
2	33.1	17.7	3500	1.05	58.8
3	35.2	20.6	3350	1.18	58.5
4	36.7	24.0	3250	1.34	58.2
5	36.8	24.6	3250	1.37	58.2
6	38.7	27.1	3250	1.51	58.1
7	39.3	25.8	3250	1.44	58.5
8	39.4	25.8	3250	1.43	58.7
9	39.7	27.1	3250	1.49	59.1
1970	42.7	29.3	3350	1.64	59.6
1	44.1	31.0	3450	1.79	59.7
2	46.4	31.9	3600	1.92	60.0
3	47.6	31.2	3748	1.94	60.2

PRODUCTIVITY TRENDS (cont'd)

Year	Ave. Payload Tons	Ton-mile/ Locomotive (000 000)	Locomotives (No.)	Ton-mile/ Mile of Track Operated (000 000's)	Miles of Track Operated (000's)
1974	47.5	32.3	3870	2.08	60.2
5	49.2	30.5	3963	2.02	60.0
6	48.7	31.0	3994	2.07	59.3
7	50.8	32.1	4021	2.19	59.0
8	51.8	33.8	4057	2.34	58.5
Text Figure	9.4	9.5	9.5	9.6	9.6

POOR

QUALITY

ORIGINAL